

27
MONTHLY NOTICES

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MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXXXI.

NOVEMBER 12, 1920.

No. 1

Professor A. FOWLER, F.R.S., PRESIDENT, in the Chair.

Arthur Edward Birch, M.A. (Oxon.), B.A. (Lond.) (late Captain, Royal Welsh Fusiliers), 24 Cambridge Road, Lee, London, S.E. 12 ;

Lieut. Arthur Frank Butcher, R.N.R., "St. Mary's," 59 Burnt Ash Road, Lee, London, S.E. 12 ;

Coert Hendrik Hins, Observatory, Leiden ; and

James S. Lewis, Curator of Airdrie Observatory, Jesmond Dene, Victoria Place, Airdrie, Scotland,

were balloted for and duly elected Fellows of the Society.

The following candidates were proposed for election as Fellows of the Society, the names of the proposers from personal knowledge being appended :—

Miss Gertrude Bacon, 57 Hyde Vale, Greenwich, London, S.E. 10 (proposed by F. W. Dyson) ;

George Percy Bailey, M.A., "Walford," Tamworth (proposed by A. L. Cortie) ;

Captain Thomas Luther Evans, F.R.G.S., Ellenboro Lodge, Whitecross Road, Weston-super-Mare (proposed by W. F. Denning) ;

Edgar William Foster, 31 Park Street West, Luton, Beds (proposed by D. R. Fotheringham) ;

Charles Frobisher, Hon. Capt. R.A.F., F.R.Met Soc., A.M.I.Ae.E., 147 West Street, Sheffield (proposed by E. Howarth) ;

Mrs. H. Periam Hawkins, St. Mary's Cottage, Reigate (proposed by T. E. R. Phillips) ;

- Rev. George Stewart Hitchcock, D.D., S.S.D., F.R.G.S., F.S.S.,
M.R.A.S., Greenfields, Frindsbury, Kent (proposed by
H. J. Adams);
- George Hooper, Marine Dept., Wellington, New Zealand
(proposed by John Browning);
- Major Arthur Everard Levin, T.D., The Croft, Bickley, Kent
(proposed by T. E. R. Phillips);
- Arthur William Long, "Campsie," 8 Main Road, Rosebank,
C.P., South Africa (proposed by H. E. Wood);
- Krishna Bindu Madhava, M.A., Asst. Professor of Mathematics,
Mysore University, Central College, Bangalore, India
(proposed by T. P. Bhaskaran);
- William Cunliffe Margerison, York House, Knaresborough,
Yorks (proposed by Duncan Milligan);
- John Paraskévopoulos, Ph.D., Assistant at the National
Observatory, Athens, Greece (proposed by E. B. Frost);
- Rev. James Peter Rowland, S.J., B.Sc. (Lond.), Stonyhurst
College Observatory, Blackburn (proposed by A. L. Cortie);
- Commander John A. Rupert-Jones, R.D., R.N.R., The Milford
Haven Dock Company, Milford Haven, S. Wales (proposed
by T. C. Hudson);
- Lieut. John Bisset Smith, R.N.R., 5774 Balsam Street,
Kerrisdale, Vancouver, B.C. (proposed by C. Eddie);
- Sydney Charles Tanner, 58 Fleming Road, Kennington Park,
London, S.E. 17 (proposed by J. E. Evans); and
- Ernest W. Verral, 2709 Mount Tolmie Road, Victoria, B.C.
(proposed by D. Baxandall).

One hundred and seventy presents were announced as having
been received since the last Ordinary Meeting, including, amongst
others, the Greenwich Catalogue of Stars, 1910.

*The Hypothetical Parallaxes of 556 Visual Double Stars, with a
determination of the Velocity and Direction of the Solar Motion.*
By J. Jackson, M.A., B.Sc., and H. H. Furner.

(Communicated by the Astronomer Royal.)

Introduction.

When the parallax and the elements of the orbit of a double
star are known, the sum of the masses of the components is
determined by

$$m_1 + m_2 = \alpha^3 / p^3 P^2 \quad . \quad . \quad . \quad (1)$$

where $m_1 + m_2$ = combined mass in terms of the sun's mass as unit,

α = semi-major axis in seconds of arc,

p = parallax in seconds of arc,

and P = period in years.

However, the number of double stars for which the required data are known is very small. The orbits of about 130 double stars have been computed, and although for a number of systems the elements are very uncertain, the value of a^3/P^2 may be considered as a fair approximation. The great difficulty is to obtain reliable values of the parallax, and this has been done for only a small fraction of the total number of systems. R. G. Aitken * has determined the mass of 21 double stars, using spectroscopic as well as trigonometric parallaxes. The mean value of $m_1 + m_2$ obtained was 1.88 with a range from 0.21 to 7.21, although the range was only from 0.45 to 3.3 for 14 systems having good trigonometric parallaxes.† R. F. Sandford and A. van Maanen ‡ have discussed 39 systems, and obtained results in fair agreement with Aitken's. They also found that the mass of the system increases slowly with the absolute magnitude, a change of 5 magnitudes corresponding to a factor of only 3 or 4 in the mass. These results are in agreement with those obtained from spectroscopic binary systems for which the range of spectral type is greater than for visual binaries. The following short table, taken from Aitken's book *The Binary Stars*, shows that the mass of systems of the earlier spectral types is larger than that of systems of the later spectral types (F and G) to which most of the visual double stars belong. As the earlier types are more luminous than the later ones, the table supports Sandford and van Maanen's results.

Class.	m_1	m_2	Number of Stars.
B to B8	12.3	8.5	9
B9 to A5	3.0	2.4	12
F5 to G	1.9	1.7	3

A greater number of stars has been treated by Russell,§ who applied statistical methods to physical pairs with parallaxes but no orbits, and to visual binaries and physical pairs with good proper motions but no parallaxes. The following table gives his results:—

Spectrum.	Spectroscopic Binaries.		Visual Binaries.		Physical Pairs.		Parallactic Motions.	
	No.	Mass.	No.	Mass.	No.	Mass.	No.	Mass.
Bo-B5	13	17.5			8	10.4	36	7.1
B8-A5	18	4.0	6	5.9	12	3.0	114	8.4
F-G, giant	34	3.9					37	8.1
K-M, giant							38	9.8
F-F5, dwarf			17	3.5	9	3.4	60	2.5
K8-Ko, dwarf			21	1.8	10	1.4	51	0.7
K5-M, dwarf			4	0.7	8	1.0		

* *Publ. A.S.P.*, 31, 196.

† *The Binary Stars*, p. 209.

‡ *Publ. A.S.P.*, 31, 231.

§ *Report of the Twenty-first Meeting of the American Astronomical Society Publications*, 3, 327; or *Popular Astronomy*, 25, 666.

In this table the first three groups present quite independent data. The fourth includes stars of the second and third groups, but is for the most part independent.

It appears from all these figures that the mean mass of the stars does not vary much from one spectral type to another. Russell's table indicates that the mean mass of binary systems consisting of dwarf stars is about twice that of the sun, while that of systems consisting of giant stars (including all the B and A class stars) is about eight times that of the sun.

Now if the mass of a binary system can be assumed, formula (1) written in the form

$$p = \frac{a}{\sqrt[3]{(m_1 + m_2)} P^2} \quad (2)$$

can be used for the determination of the parallax. As $m_1 + m_2$ appears in the formula through its cube root, an error of factor 8 in the assumed mass will produce an error of factor only 2 in the parallax. As one of the greatest needs of stellar astronomy at the present time is the determination of accurate parallaxes—i.e. parallaxes for which the probable error is a fairly small fraction of the whole amount,—it seems justifiable to employ formula (2) for the calculation of them.

Before we assume a mass to apply to formula (2) we must investigate the variation to be expected in the value of $\frac{1}{\sqrt[3]{m_1 + m_2}}$ from system to system. The following values have been determined from the sources stated:—

	Spec. Type.	No. of Stars.	$\frac{1}{\sqrt[3]{m_1 + m_2}}$
Aitken, <i>Binary Stars</i> , p. 209		14	$0.89 \pm .14$
„ <i>Publ. A.S.P.</i> , 31, 196		7	$0.92 \pm .20$
Sandford and van Maanen,	A	6	$0.68 \pm .18$
<i>Publ. A.S.P.</i> , 31, 231	F	18	$0.80 \pm .23$
	G	8	$0.87 \pm .12$
	K	5	$0.92 \pm .05$
	M	2	1.18

As a mean value we have considered 0.855 the best.

However, it is a general practice to take $m_1 + m_2 = 2$, and we have decided to do this in deriving the hypothetical parallax of double stars with orbit determinations, and the results are given in Table I. at the end of this paper. If it is desired to change the hypothetical parallaxes to correspond to a value of 0.855 for

$\frac{1}{\sqrt[3]{m_1 + m_2}}$, the parallaxes of Table I. have to be multiplied by 1.077 and the absolute magnitudes have to be made $0^m.16$ fainter.

For the formation of Table I. the elements of the orbits have been obtained from Aitken's book *The Binary Stars*, from a few papers published recently by various astronomers, and from the

sources indicated in part ii. of Burnham's General Catalogue of Double Stars.

The successive columns of Table I. give (1) the number of the star in Burnham's General Catalogue, (2) the Harvard spectral type, (3) the Harvard visual magnitude, (4) the absolute magnitude derived from the Harvard magnitude and the hypothetical parallax, (5) the hypothetical parallax. We must here express our thanks to Professor Bailey and Miss Cannon, who kindly supplied us with advance proofs of the Henry Draper Catalogue of Stellar Spectra to 15 hours of R.A. and the spectral types and magnitudes of stars after 15 hours in manuscript.

The last six stars are too far south to be included in Burnham's Catalogue, and we have given the number in Innes's Reference Catalogue of Southern Double Stars in the first column of Table I.

Double Stars without Orbit Elements.

There are many double stars for which relative motion of the components has been observed, but for which the observed arc is too small to permit the computation of orbit elements. In discussing the double-star observations made at Greenwich since 1893, we have ascribed slow orbital motion to 452 pairs, and the question arises as to how far this material can be used for the investigation of the systems concerned. For the application of formulæ (1) and (2) the only function of the elements required is a^3/P^2 , and it appears that this can be determined with reasonable accuracy even when there is great uncertainty as to the elements as a whole. The reason why quite different sets of elements give approximately the same value of a^3/P^2 is that these elements give nearly the same arc for that portion of the orbit which has been observed, and that this arc is sufficient to determine the gravitational attraction between the two stars. In fact, the relation between the mass and parallax of the system may be considered simply as a function of the departure of the relative motion from rectilinear motion. Only three complete observations are theoretically necessary to determine this. Hypothetical parallaxes were computed by Russell and Hertzsprung from arcs as early as 1911. We proceed to discuss this point in some detail.

Take the unit of time as the year, and the unit of mass that of the sun. Let p be the parallax, and ρ, θ the observed separation and position angle of a double star. If $m_1 + m_2$ be the mass of the system and i the angle between the true radius vector and the line of sight, then the equation of motion for the projected radius vector is

$$\frac{1}{p} \cdot \frac{d^2 \rho}{dt^2} - \frac{\rho \left(\frac{d\theta}{dt} \right)^2}{p^2} = - \frac{4\pi^2 (m_1 + m_2) \sin^3 i p^2}{\rho^2},$$

which can be written in the form

$$\frac{p^3}{\rho^3} = \frac{1}{4\pi^2 (m_1 + m_2) \sin^3 i} \left[\left(\frac{d\theta}{dt} \right)^2 - \frac{1}{\rho} \cdot \frac{d^2 \rho}{dt^2} \right]. \quad (3)$$

or, if θ is measured in degrees instead of radians,

$$\frac{p^3}{\rho^3} = \frac{1}{(m_1 + m_2) \sin^3 i} \left[\left(\frac{1}{360} \frac{d\theta}{dt} \right)^2 - \frac{1}{4\pi^2 \rho} \frac{d^2 \rho}{dt^2} \right].$$

If $\rho_1 \theta_1, \rho_2 \theta_2, \rho_3 \theta_3$ refer to times $t_0 - \frac{1}{2}t, t_0, t_0 + \frac{1}{2}t$, we can write approximately

$$\frac{d\theta}{dt} = \frac{\theta_3 - \theta_1}{t}, \quad \frac{d^2 \rho}{dt^2} = \frac{4(\rho_1 + \rho_3 - 2\rho_2)}{t^2},$$

so that

$$\frac{p^3}{\rho^3} = \frac{1}{(m_1 + m_2) t^2 \sin^3 i} \left[\left(\frac{\theta_3 - \theta_1}{360} \right)^2 + \frac{2\rho_2 - \rho_1 - \rho_3}{\pi^2 \rho} \right] \quad (4)$$

Equation (4) contains, besides the quantities derived from the observations, three unknowns, $p, m_1 + m_2, i$. If it is to be used for the calculation of p , we must find values to substitute for $\frac{1}{\sqrt[3]{m_1 + m_2}}$ and $\text{cosec } i$. We have already discussed the value of the first of these quantities in connection with double stars for which orbit elements are known, and we must now deal with the second. Assuming that the distribution of radii vectores is quite independent of the direction of the line of sight, the mean value of $\text{cosec } i$ for a large number of stars will be $\frac{\pi}{2}$ or 1.57. For any particular star $\text{cosec } i$ cannot be less than 1. If the value is really 1, the parallax obtained by using the mean value will be 1.57 times the true amount, and the absolute magnitude deduced will be 1^{m.0} too faint. This is the maximum error possible in this direction. If i be 10° (or 20°) the parallax deduced by using a mean value for $\text{cosec } i$ will be 3.7 (or 1.5) times too small, and the absolute magnitude will be 2^{m.8} (or 0^{m.8}) too bright. However, the probability of i being so small as 10° (or 20°) is only 15 (or 60) in 1000. Moreover, really small values of i in particular stars should be discovered by the nature of the relative motion. For such values can only occur when (1) the orbit plane passes near the line of sight, and (2) the companion is in that part of its orbit nearly in the line from the principal star to the sun. The motion of the companion will therefore be approximately rectilinear motion passing very close to the principal star. We may therefore take it that only in very exceptional cases will the error introduced by using a mean value of $\text{cosec } i$ exceed 50 per cent. in the parallax or 1^{m.0} in the absolute magnitude.

In applying (4) to the determination of hypothetical parallaxes we have therefore put $\text{cosec } i = 1.57$, and adopting $\frac{1}{\sqrt[3]{m_1 + m_2}} = 0.855$ we find

$$p = \frac{1.34\rho}{t^{\frac{2}{3}}} \left[\left(\frac{\theta_3 - \theta_1}{360} \right)^2 + \frac{2\rho_2 - \rho_1 - \rho_3}{\pi^2 \rho} \right]^{\frac{1}{3}} \quad (5)$$

This formula has been used for those stars for which the observations yielded satisfactory values of $\theta_3 - \theta_1$ and $2\rho_2 - \rho_1 - \rho_3$. The observations employed were taken from Burnham's General Catalogue; Lewis's Memoir on the Struve Double Stars; Aitken's observations in *Publications of the Lick Observatory*, vol. xii.; Doolittle's observations in *Publications of the University of Pennsylvania*, Astr. Series, vol. iv., part i.; Fox's observations in *Annals of the Dearborn Observatory*, vol. i.; van Biesbroeck's observations in *Annales de l'Observatoire Royale de Belgique*, vols. ix., xiii.; the Greenwich observations which have been collected and will be published in a special volume, together with observations published recently in the *Astronomical Journal* and the *Monthly Notices*. The values of θ were plotted against the time in one diagram, and where the observations seemed to warrant it the values of ρ were plotted against the time in another diagram. In practically all cases for which a hypothetical parallax is given $\frac{d\theta}{dt}$

had a non-zero value. In a few cases for which no certain change of θ was found the hypothetical parallax was computed from the change of ρ by a formula to be given later (6). In all but a few cases the change of θ during the interval covered by the observations exceeded 5° . In cases where the observations covered a relatively large arc, as e.g. 90° , several values of the parallax were computed from different parts of the arc and an average was taken. No corrections were applied to the observations of either ρ or θ , but in the case of Otto Struve's observations both the observed and the corrected angles were plotted, and the best curve was often found to pass between the points plotted. It should be added that greatest weight was given to special observers such as W. Struve and Dembowski, and that attention was paid to the number of nights.

The chief drawback to the extensive use of formula (5) is the difficulty of determining the variation of ρ . The observations are affected by relatively large errors, both accidental and systematic. In many cases variation of ρ could only be asserted through change in the value of $\frac{d\theta}{dt}$. It will, indeed, often be more accurate to

determine the value of $\frac{d^2\rho}{dt^2}$ by means of $\frac{d\theta}{dt}$, $\frac{d^2\theta}{dt^2}$, $\frac{d^3\theta}{dt^3}$ than from the actual observations of ρ . The necessary formula can be obtained by differentiating twice the equation $\rho^2 \frac{d\theta}{dt} = \text{constant}$. However, it appears that $\frac{d^2\rho}{dt^2}$ can be neglected, when it cannot be obtained from the observations, without introducing serious systematic errors in the result.

The average value of $\frac{d^2\rho}{dt^2}$ taken round any orbit is zero. But the way in which $\frac{d^2\rho}{dt^2}$ enters into formula (5) is such as to make

it difficult to estimate the average error introduced into the deduced parallax by the assumption that the second term in the square bracket can be neglected. Thus the mean value of $-\frac{1}{\rho} \frac{d^2\rho}{dt^2}$ for a time T is

$$-\frac{1}{T} \int \frac{1}{\rho} \frac{d^2\rho}{dt^2} dt = \frac{1}{T} \left[-\frac{1}{\rho} \frac{d\rho}{dt} \right] - \frac{1}{T} \int \frac{1}{\rho^2} \left(\frac{d\rho}{dt} \right)^2 dt.$$

Now the integrated term vanishes for a complete revolution, and the second term has clearly a negative value. It might therefore be expected that the neglect of this term would lead to systematically large values of the parallax. This error is diminished, to some extent at least, by the extraction of the cube root; also $-\frac{1}{\rho} \frac{d^2\rho}{dt^2}$

is negative only on that side of the latus rectum which includes the periastron. (We are here discussing the Keplerian and not the projected ellipse.) The mean negative value of this quantity is therefore due to a relatively small number of large negative values. For the greater portion of the period of revolution the companion is in the part of its orbit for which $-\frac{1}{\rho} \frac{d^2\rho}{dt^2}$ is positive,

and the observations are most likely to lie in that part of the orbit, for then the separation of the components is greatest. As the cube root of the expression in square brackets of formula (4) has to be taken, the neglect of $\frac{d^2\rho}{dt^2}$ can only have a large effect on the

deduced value of p when the two terms nearly cancel, *i.e.* when the system is very distant. Such systems are probably not very numerous amongst those considered here. $\frac{d^2\rho}{dt^2}$ has therefore been

neglected without applying any factor to allow for it, for those stars for which it cannot be determined from the observations. The neglect of this term reduces this formula, for those stars in which $\frac{d\rho}{dt}$ is zero, to the same form as (6) below.

The formula first put forward by Russell and Hertzsprung for the determination of hypothetical parallaxes is suitable for those stars for which the observations suffice to give definite positions at two epochs. Formula (5) depends on positions at three epochs, although in the simplified form, when $\frac{d^2\rho}{dt^2}$ is neglected, it depends only on the position angle at two epochs and a value of the separation. Both Russell's and Hertzsprung's formulæ may be written in the form

$$p = a \sqrt[3]{\rho v^2} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (6)$$

where ρ is the separation, v the annual relative velocity of the components in seconds of arc, and a is given a mean value. This

formula is really derived from the energy equation of elliptic motion, which is usually written

$$V^2 = 4\pi^2(m_1 + m_2)\left(\frac{2}{r} - \frac{1}{a}\right),$$

where V is the linear velocity, r the radius vector, and a the semi-major axis in terms of the astronomical unit of length. This formula can be written

$$\frac{v^2}{p^2 \sin^2 i_2} = \frac{4\pi^2(m_1 + m_2) p \sin i_1}{\rho} \left(2 - \frac{r}{a}\right)$$

or

$$p^3 = \frac{\rho v^2}{4\pi^2(m_1 + m_2) \sin i_1 \sin^2 i_2 (2 - r/a)},$$

where v is the annual relative velocity in seconds of arc, i_1 the angle between the true radius vector and the line of sight, and i_2 the angle between the true direction of relative motion and the line of sight. a therefore is given by

$$\frac{1}{a^3} = 4\pi^2(m_1 + m_2) \sin i_1 \sin^2 i_2 \left(2 - \frac{r}{a}\right).$$

From 25 stars of known parallax Hertzsprung* determined the value of a as 0.434, with a probable error as the factor 1.46. Russell† computed from the principles of geometrical probability that

$$a = \frac{1}{\sqrt[3]{14.6(m_1 + m_2)}} = 0.325 \text{ or } 0.350, \text{ according as we assume}$$

$$m_1 + m_2 = 2 \text{ or } \frac{1}{\sqrt[3]{m_1 + m_2}} = 0.855.$$

Russell gives no details of his determination of the value of

$\frac{1}{\sqrt[3]{4\pi^2 \sin i_1 \sin^2 i_2 (2 - r/a)}}$ from the theory of probability. If we assume the three variable factors to be independent, we get the mean value of

$$\frac{1}{\sqrt[3]{\sin i_1}} = \frac{\sqrt{\pi}}{2} \frac{\Gamma(\frac{5}{6})}{\Gamma(\frac{4}{3})} = 1.120$$

and the mean value of

$$\frac{1}{\sqrt[3]{\sin^2 i_2}} = \frac{\sqrt{\pi}}{2} \frac{\Gamma(\frac{2}{3})}{\Gamma(\frac{7}{6})} = 1.294.$$

The mean value of $\frac{1}{\sqrt[3]{2 - r/a}}$ cannot differ much from unity. If

e be the eccentricity of the orbit and E the eccentric angle, the mean value of this factor is

$$\frac{1}{\pi} \int_0^\pi \frac{(1 - e \cos E) dE}{(1 + e \cos E)^{\frac{1}{2}}},$$

* *Astronomische Nachrichten*, 190, 113.

† *Pop. Ast.*, 22, 332; or *Publ. Amer. Astr. Soc.*, 3, 42.

and if we expand in powers of e and integrate we get

$$1 + \frac{5}{18}e^2 + \frac{77}{648}e^4 + \dots$$

We now assume that this can be integrated as an infinite series for all values of e from 0 to 1 and get from the first few terms $1 + \cdot 093 + \cdot 024$. From which we may assume a mean value of

$\frac{1}{\sqrt[3]{2 - r/a}}$ of 1.13. Hence we get the value for a if we take

$$\frac{1}{\sqrt{m_1 + m_2}} = 0.855 \text{ as}$$

$$0.855 \times 0.426 \times 1.13 = 0.411,$$

which lies between Russell's and Hertzsprung's values.

Again, if the orbit is circular we can put $v = \rho \frac{d\theta}{dt}$, $\frac{d^2\rho}{dt^2} = 0$, and in this case (3) can be written

$$p^3 = \frac{\rho v^2}{4\pi^2(m_1 + m_2) \sin^3 i},$$

or, using the constants of formula (4), $p = 0.397 \sqrt[3]{pv^2}$.

In applying formula (6) for the calculation of hypothetical parallaxes we have taken a as 0.397. This appears to be a reasonable mean of the various values we have found for a , and it makes formulæ (5) and (6) agree numerically for those stars for which no certain change in the value of ρ has been observed. We may say that in general (6) has been preferred to (5) for stars in which $\frac{d\rho}{dt}$ had a definite value, but for which no definite value could be assigned to $\frac{d^2\rho}{dt^2}$. For some stars (5) and (6) were both applied, and in these cases the hypothetical parallax given is a mean of the two determinations.

The results obtained are given in Table II. This table is of the same form as Table I. and does not need any further explanation. It contains 456 stars, but 24 of these are also contained in Table I. There are therefore 556 different systems in all. In the following discussions the 24 systems common to the two tables have been included twice.

Comparison of Hypothetical Parallaxes with Trigonometric Parallaxes and Spectroscopic Parallaxes.

The material for this comparison is given in Table III. The hypothetical parallaxes of the first 69 stars are taken from Table I., and depend on complete orbit elements; those of the last 25 stars are taken from Table II., and depend on arcs of orbits only. The

spectroscopic parallaxes are taken from Adams' and Joy's "Luminosities and Parallaxes of Five Hundred Stars."* For the trigonometric parallaxes only the best determinations have been used, and where there are several determinations the simple mean has been taken irrespective of the probable error given. To reduce the parallaxes from relative to absolute ".003 or ".004 has been added. The last column of Table III. gives the number of determinations on which the trigonometric parallax depends: the word "Spec." in this column denotes that the parallax is determined from the fact that the star is both a visual and a spectroscopic binary.

We will consider the trigonometric parallaxes first and divide the stars into four groups. For the first three groups the hypothetical parallaxes depend on orbit elements and the stars are divided into groups according to the magnitude of the hypothetical parallax. For the last group of stars the hypothetical parallax depends on an arc of an orbit. The mean parallax for each group is given, as also the number of stars in the group.

	No. of Stars.	Hyp. Par.	Abs. Trig. Par.	Hyp.-Trig.	Hyp. Par. < Trig. Par.
Hyp. par. greater than ".050	29	".137	".152	-.015	17
Hyp. par. between ".025 and ".050	20	".035	".035	.000	9
Hyp. par. less than ".025	19	".019	".023	-.004	13
Hyp. par. from arc of orbit only	25	".045	".036	+.009	7
Total	93	".066	".069	-.003	46

It will be seen from this table that the hypothetical parallaxes are on the whole rather less than trigonometric, although the opposite is the case for those stars for which only an arc of the orbit is available.

We now deal with stars for which a spectroscopic parallax is available in the same way, only as there are fewer stars we combine the second and third groups.

	No. of Stars.	Hyp. Par.	Spec. Par.	Hyp. Spec.	Hyp. Par. < Spec. Par.
Hyp. par. greater than ".050	22	".109	".126	-.017	16
Hyp. par. less than ".050	10	".032	".049	-.017	8
Hyp. par. from arc of orbit only	11	".059	".058	+.001	7
Total	43	".078	".090	-.012	31

These comparisons seem to indicate that on the whole the hypothetical parallaxes given in this paper are a little too small, especially amongst the nearer stars. We shall see later that the nearer stars contain a large majority of late type stars. These tables, therefore, indicate that the late type stars are less massive than the mean.

* *Mount Wilson Contributions*, No. 142; or *A.P.J.*, 46, 313.

The Solar Motion.

When the parallax of a star is known its proper motion can be converted into linear motion, and our first application of the hypothetical parallaxes will be to determine the mean velocity of the sun relative to the stars considered. If the velocity comes out too small it will indicate that our parallaxes are too large, and if this be attributed to an error in the assumed mean mass, it will indicate that the mass we have used is too small.

As usual, we will take the x -axis directed towards the first point of Aries, the y -axis towards a point on the equator at 6^h of R.A., and the z -axis towards the north pole. Let X , Y , Z be the reversed components of the solar motion measured in astronomical units per year. Then, considering the proper motion of the stars as entirely due to the sun's motion, we have for a star in R.A. α and Dec. δ the equations

$$\left. \begin{aligned} -X \sin \alpha + Y \cos \alpha &= \frac{1}{p} \mu_{\alpha} \cos \delta \\ -X \cos \alpha \sin \delta - Y \sin \alpha \sin \delta + Z \cos \delta &= \frac{1}{p} \mu_{\delta} \end{aligned} \right\} \quad (7)$$

where μ_{α} , μ_{δ} are the proper motions in R.A. and Dec.

Of the 124 stars for which we have orbit elements we have found proper motions for 119. The greater portion of these were obtained from Boss's Preliminary General Catalogue. Others were obtained from the *Publications of the Cincinnati Observatory*, No. 18, part 4, and the *Greenwich Catalogue* for 1910. A few were specially computed. Each star was treated separately, and the normal equations obtained were

$$\left. \begin{aligned} +77.62X - 2.07Y + 0.64Z &= -37.03 \\ -2.07X + 73.09Y + 3.50Z &= +226.16 \\ +0.64X + 3.50Y + 87.29Z &= -151.98 \end{aligned} \right\} \quad (8)$$

which give $X = -0.38$, $Y = +3.17$, $Z = -1.87$. The apex of the solar motion from these figures is in R.A. $276^{\circ}.8$, Dec. $+30^{\circ}.3$, and the speed 3.70 astronomical units per annum, or 17.54 kilometres per second.

Of the 456 stars in Table II. the proper motions of 208 are given in one or more of the three catalogues mentioned above, and these were used to determine the solar motion. The stars were not treated separately, but arranged in 16 groups of 13 stars each as follows. They were first divided into 8 groups of 26 stars each according to R.A. Then each group was divided into two, the more northerly stars going to the one part and the more southerly to the other. As the stars are nearly all included between Dec. -10° and $+60^{\circ}$, each group of stars lies approximately in an area extending 3^h in R.A. and 35° in Dec. In each group the means of the quantities μ_{α}/p , μ_{δ}/p and the mean of the R.A.'s and Dec.'s were taken for substitution in (7). The normal equations

for X, Y, Z were then built up. The equations, which require multiplication by 13 to correspond to (8), were found as follows:—

$$\left. \begin{aligned} +9.85X + 0.42Y + 0.14Z &= +0.66 \\ +0.42X + 9.31Y + 0.15Z &= +31.40 \\ +0.14X + 0.15Y + 12.84Z &= -30.66 \end{aligned} \right\} \quad . \quad . \quad (9)$$

giving $X = -0.04$, $Y = +3.41$, $Z = -2.43$. These give the position of the apex of the solar motion R.A. $270^{\circ}.6$, Dec. $+35^{\circ}.4$, and the speed as 4.19 astronomical units per annum, or 19.85 kilometres per second.

When equations (8) and (9) are combined so as to give equal weight to each of the 327 stars we get

$$X = -0.17, Y = +3.33, Z = -2.24,$$

and for the apex of the solar motion

R.A. $273^{\circ}.0$, Dec. $+33^{\circ}.8$, speed 19.13 kilometres per second.

The principal points to note about this method are that it gives equal weight to each star and that it utilises the magnitudes of all the proper motions without rejecting any as excessively large. In a further discussion of the 208 stars of Table II. for which good proper motions are available, the stars were divided into the same 16 groups, but instead of taking the mean values of μ_a/p and μ_s/p , the sum of the proper motions was divided by the sum of the parallaxes. In this way each group of 13 stars was equally weighted, but the individual stars in a group were not equally weighted. This method tended to eliminate errors in the proper motions, and to a lesser extent in the hypothetical parallaxes, but it gave an excessively large weight to the nearer stars. Thus the star P.G.C. 4972, with a hypothetical parallax of $0''.209$ and an annual proper motion of $-0^s.1728$ and $-0''.638$, dominated its group. The results obtained by including and excluding the star were respectively—

R.A. $260^{\circ}.7$ Dec. $+36^{\circ}.7$ Speed 18.6 kilometres per second.

R.A. $268^{\circ}.3$ Dec. $+40^{\circ}.9$ Speed 17.3 kilometres per second.

It is considered that the result

R.A. $273^{\circ}.0$ Dec. $+33^{\circ}.8$ Speed 19.13 kilometres per second

best represents the motion which can be deduced from the material discussed.

This result agrees well with the speed of the solar motion found by W. W. Campbell* from the radial velocities of 1193 stars measured spectroscopically. His result was 19.5 kilometres per second. The agreement of our results with this value indicates that our assumptions are not seriously in error.

Absolute Magnitudes and Spectral Types.

The fourth column of Tables I. and II. gives the absolute magnitudes of the stars. These magnitudes are derived from the

* *Lick Obs. Bulletin*, No. 196.

Harvard visual magnitudes, and correspond to a parallax of 0".1. They are therefore given by

$$M = m + 5 \log p + 5.$$

The absolute magnitude of the sun on this scale is 4.7.

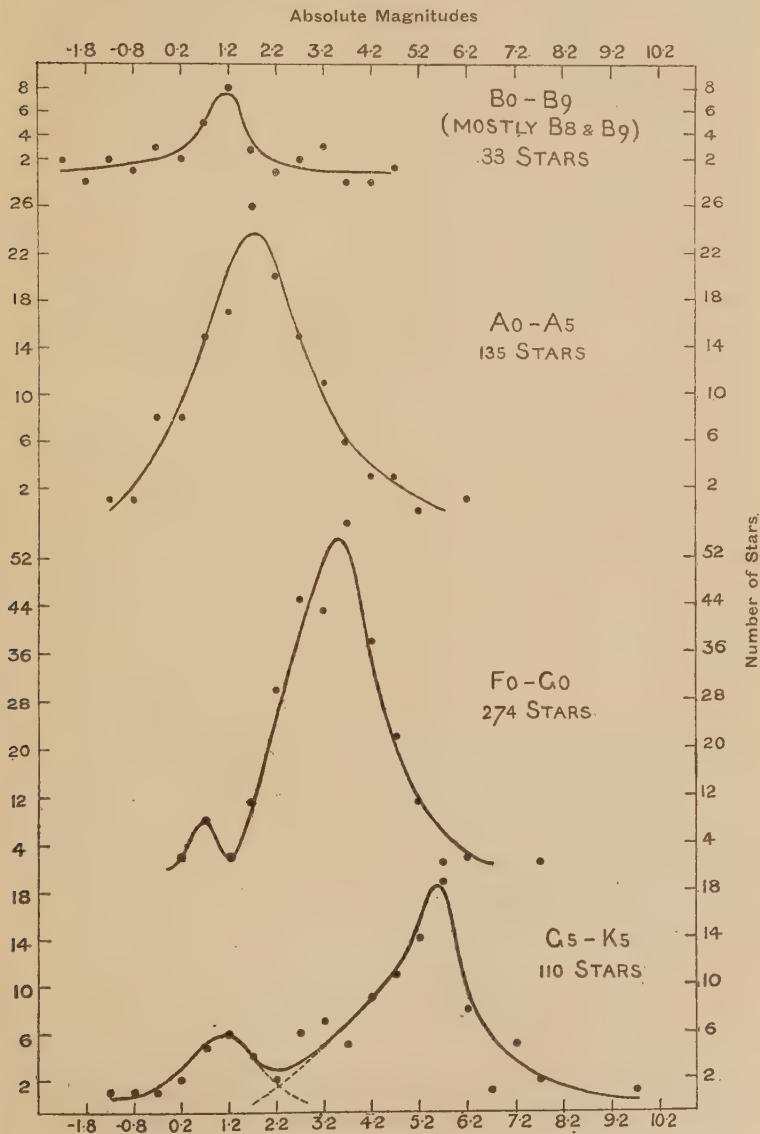
The combined magnitude of the components is generally given, but when the two (or more) stars are given separately in the Harvard volumes the absolute magnitudes have been derived separately. In the following discussion, however, the magnitudes have been combined, except when different spectral types are given for the components. If the two components are equal, each is 0^m.75 fainter than the combined magnitude; in all other cases the magnitude of the brighter star is more nearly equal to the magnitude given.

The following table gives the number of stars of different spectral types for each half magnitude. On the left the spectral type is given, and at the top of each column the limiting magnitudes of the stars.

	< -1.0		-1.0 to -0.5		-0.5 to 0.0		0.0 to 0.5		0.5 to 1.0		1.0 to 1.5		1.5 to 2.0		2.0 to 2.5		2.5 to 3.0		3.0 to 3.5		3.5 to 4.0		4.0 to 4.5		4.5 to 5.0		5.0 to 5.5		5.5 to 6.0		6.0 to 6.5		6.5 to 7.0		7.0 to 7.5		7.5 to 8.0		> 8.0
	-0.6 to -0.1		0.1 to 0.4		0.4 to 0.9		0.9 to 1.4		1.4 to 1.9		1.9 to 2.4		2.4 to 2.9		2.9 to 3.4		3.4 to 3.9		3.9 to 4.4		4.4 to 4.9		4.9 to 5.4		5.4 to 5.9		5.9 to 6.4		6.4 to 6.9		6.9 to 7.4		7.4 to 7.9		7.9 to 8.4		> 8.4		
Oe5				I																																			
Bo	2																																						
B2p	I																																						
B3					I		I	I								I																							
B5								2																															
B8	I	I	2							3				I	I																								
B9				I		2	4	3								3							I																
Ao		I	2	4	8	8	12	5	7	2	2																												
A2	I		4	4	4	7	9	9	5	3	2	1	I																										
A2p														I	I																								
A3				I		I	I	4	4	2	3	I											I																
A5			I		2	I	I	I	I		3	I	2	I																									
Fo					4	I	3	9	7	8	3	I																											
Fop														I	I																								
F2				I	2		4	6	8	2	6	2	2	I																									
F5					I		3	8	18	16	16	17	3																										
F8					I		I	4	7	6	17	7	9	2																									
Go				I																																			
G5				I	2	4	2	I	I	5	4	6	7	6	11	8	8	I																					
Ko	I	I	I	I	3	I	2	I	5	2	I	3	4	7	7																								
K2								I																															
K5																																							
Ma																																							
Mb				I	I																																		
Oe5-B9	4	I	3	2	5	8	3	I	2	3																													
Ao-A5	I	I	8	8	15	17	26	20	15	11	6	3	3																										
Fo-Go				2	8	2	11	30	45	43	58	38	22	11	I																								
G5-K5	I	I	I	2	5	6	4	2	6	7	5	9	11	14	19	8	I																						
Ma-Mb				I	I																																		

The number of stars for each half magnitude is also shown in the diagram. The spectral types have been grouped together in the manner shown at the bottom of the table.

Frequency Curves of Absolute Magnitudes for different Spectral Types.



The results on the whole give a general confirmation of the views put forward by Russell and Hertzsprung in support of a division of the stars into dwarfs and giants. Before giving a more detailed description of our results, we may state the following differences that we find from Russell's results:—*

(1) The magnitudes of the A stars extend to about one magnitude fainter. This could be explained by assuming the A stars of mass 8 instead of 2.

(2) The change of mean absolute magnitude of dwarf stars as we pass from one spectral type to another is not so great. This also could be explained by assuming the dwarf stars less massive than the sun.

(3) There is a considerable number of Ko stars intermediate between the giants and dwarfs.

Our results may be summarised as follows:—

All the 33 stars classed Oe5-B9 are bright; the 4 fainter than $3^m.0$ are all classed as B9. The two brightest stars of magnitudes -2.1 , -1.1 are in the B0 class. Most of the stars in this class are B8 or B9. The number of stars is rather small, but we may say that there is a maximum frequency about magnitude 1.1 . Typical B0 stars are probably much brighter than this.

There are 135 stars classed A0-A5. Of these 93 are between $0^m.5$ and $2^m.9$, and none differ very widely from this. There is one star of magnitude 6.3. The maximum frequency is at magnitude 1.8.

None of the F stars have extreme magnitudes. There are 118 stars classed as G0 and G5, but it appears better to separate these two sub-classes. The G0 stars show an ordinary distribution about a mean magnitude of 3.8, while the G5 stars appear to show some traces of a division into giants and dwarfs. There is a deficiency of G5 stars of the mean magnitude as compared with the G0 stars. We have therefore classed 274 stars of types F0-G0 together. A few of the brighter stars may be considered as giants relatively to the others, but the great majority appear to belong to one group with a maximum frequency about magnitude 3.5.

There are 110 stars in classes G5 to K5 consisting of stars of all magnitudes from -1 to $+7$. There is a maximum frequency about magnitudes 1.1 and 5.0 . The separation into giants and dwarfs is by no means complete, at least for G5 and Ko stars, which form the bulk of those considered here. 22 of these stars are giants and the rest dwarfs.

There are 2 giant and 2 dwarf M type stars.

The Distribution of the Stars in Space.

We must now consider the nature of the material in Tables I. and II., so as to find if any special selection of the stars has been made. The stars given in Table I. are mostly confined to those parts of the sky visible from northern latitudes. Most of them

* *Publ. of Amer. Ast. Soc.*, 3, 22; or *Pop. Ast.*, 22, 275.

therefore lie north of Dec. -10° , and only 6 are south of -30° . Otherwise they appear to be scattered at random, and to have suffered the same selection as the stars of Table II. The distribution of stars of Table II. is dependent on the Greenwich observing programme, and to some extent on the observing conditions. The stars lie mostly between Dec. -10° and $+60^{\circ}$, and as the worst weather usually occurs in late winter, there is a deficiency of stars about 5^h of R.A. The programme included most pairs between the limits of declination stated above, which were known to be in relative motion. In this way most of the double stars in the region for which the relative motion was considerable should be included. On the other hand, many double stars for which the relative motion was rather small would probably be missed. But as special attention was given to the Struve stars, it is hoped that the majority of double stars for which there is decided relative motion have been included. In any case, there has been no selection with regard to spectral type, and although pairs fainter than 7.0 apparent magnitude may have received less attention than those brighter than this, yet there is probably no serious loss from this cause till we get to magnitude 8.0 .

The following table gives the number of stars for each half magnitude of apparent brightness from 3.0 to 9.0 for those stars contained in the Harvard volumes. There are 16 stars brighter than 3.0 , 5 fainter than 9.0 , and 30 for which we have no Harvard magnitudes. The latter must be nearly all between magnitudes 8.5 and 9.5 . The table refers to the combined magnitude of the components.

Apparent magnitudes	3.00-3.49	3.50-3.99	4.00-4.49	4.50-4.99	5.00-5.49	5.50-5.99
No. of stars	5	18	14	25	37	48
Apparent magnitudes	6.00-6.49	6.50-6.99	7.00-7.49	7.50-7.99	8.00-8.49	8.50-8.99
No. of stars	50	75	78	68	71	40

The increase in the number of stars as we pass from any magnitude to a fainter one is much smaller than for the stars taken as a whole. This is probably due more to the exclusion of distant bright stars than of stars intrinsically faint but relatively near. The following argument indicates that the tables include a large proportion of the double stars in the part of the sky considered, which are as bright as $8^m.5$ apparent magnitude and have a parallax as large as $0''.01$, except so far as such stars were excluded from the Greenwich observing programme.

Consider a double star of mass 2 and parallax $0''.01$. Formula (1) will give the period for different values of the semi-major axis a . The following table gives the number of years required for a relative motion of 1° , for different values of a :—

a .	Years.	a .	Years.
$1''.00$	2.0	$4''.00$	15.7
$2''.00$	5.6	$5''.00$	22.0
$3''.00$	10.2		

About 1830 Struve examined all stars in the part of the sky we are considering down to about magnitude 8.5. It appears from the above table that stars with a parallax as large as $0''.01$ should have moved appreciably in the interval if the separation were not greater than $4''.00$. Struve undoubtedly missed many of the closer pairs, say with a separation of $1''.0$, but motion of such pairs with a parallax of $0''.01$ should be detected in 30 years or so. It may be worth mentioning that 47 per cent. of Table I. and 61 per cent. of Table II. are Struve stars. The double stars with a parallax as great as $0''.01$ and as bright as 8.5 apparent magnitude which we have missed will include those with a separation of the order of $5''.00$ or more for which the period must be of the order of 7000 years or more. The lapse of long intervals of time will be required to reveal these.

An important result is obtained by counting the number of stars in the tables between definite limits of parallax. This is done in the following table, which shows also a separation of the stars into spectral types. The total includes stars for which no spectral types are available. In one or two cases the total is smaller than the sums; this is due to the same binary being included under two different spectral types.

Parallax.	Oe-B9.	Ao-A5.	Fo-Go.	G5-M.	Total.	Thousands of Cubic Parsecs per Star.*
$>0''.1$	0	1	5	9	14	0.31
$''099-''080$	0	1	3	2	6	0.66
$''079-''060$	0	0	17	6	23	0.50
$''059-''040$	0	3	25	20	48	1.00
$''039-''030$	0	10	19	15	50	1.90
$''029-''025$	1	7	24	8	43	2.8
$''024-''020$	1	9	44	14	69	4.1
$''019, ''018$	3	7	18	6	33	6.5
$''017, ''016$	3	9	21	5	39	8.8
$''015, ''014$	0	20	17	4	42	13.8
$''013, ''012$	9	7	27	4	53	19.8
$''011, ''010$	2	15	24	8	54	38.1
$''009, ''008$	8	21	19	1	48	103
$''007, ''006$	4	15	16	8	42	352
$<''006$	2	9	2	2	16	

This table shows that the majority of the nearer stars are of late spectral type, and that the stars of Tables I. and II. thin out rapidly as we proceed to remote portions of space. This has a simple explanation which is confirmed in the section dealing with absolute magnitudes, namely, that the great majority of the intrinsically

* Assuming we are dealing with the whole sphere.

faint stars are of late spectral type, and only those which are very near our system have been observed.

We have no reason to suspect that our material is not homogeneous with regard to spectral type in relation to apparent magnitude, *i.e.* one spectral type should have suffered proportionately to another in the loss of stars on account of their appearing faint to us. The proportion of stars of apparent magnitude 8.5, for example, lost amongst K stars, should be the same as that amongst the B stars. Now at a distance of 100 parsecs (parallax 0".01) stars will appear 5 magnitudes fainter than the absolute magnitude. As maximum frequency for the B and A stars has been found at magnitudes 1.1 and 1.8 absolute, the maximum frequency for such stars at 100 parsecs should be at magnitudes 6.1 and 6.8 apparent. Hence but few B and A stars within 100 parsecs should be lost on account of faintness. But for F stars a maximum frequency was found about magnitude 3.5 absolute, corresponding to 8.5 apparent at 100 parsecs. At this apparent magnitude the proportion of stars lost begins to be very serious, and we cannot but conclude that there must be many more F stars within a distance of 100 parsecs which have been lost on account of their faintness. In fact, had these stars not been lost, the maximum frequency would have been found for a fainter absolute magnitude, so that the loss is still more serious than at first sight appears. We are, in fact, dealing with the more brilliant F stars in the region considered. For the K stars the loss within 100 parsecs must be enormous. We have found a maximum frequency at magnitude 5.0 absolute, corresponding to 10.0 apparent at 100 parsecs. Practically all such stars would be lost.

We have already concluded that, except for the loss of stars through apparent faintness, the list of stars is about uniformly complete to parallax 0".01. But the density of stars in our tables is about 100 times as great within the first 10 parsecs as at 100 parsecs. We have reason to believe that this change is not due to the loss of B or A type stars which are sufficiently bright to attract attention at 100 parsecs. It must be due in large measure to F, G, K, and M type stars, which in increasing degree become hopelessly lost at a distance of 100 parsecs.

Even the following table does not do justice to the late type stars, but it may help to indicate the extent to which they outnumber the B and A type stars. The table gives the number of stars of different types to certain limiting parallaxes, together with numbers proportional to the volume of the sphere extending to these parallaxes.

Type.	Limiting Parallax.	No. of Stars.	Vol. of Sphere.	Computed No. of Stars in Vol. 1000.
B	".010	19	1000	19
A	".010	89	1000	89
F	".025	93	64	1453
K	".040	37	16	2312

We are inevitably driven to the conclusion that the stars which attract attention on account of their apparent magnitude form only a small fraction of the total stars in space, that these are brilliant orbs scattered at large distances apart, and that intermingled with them is a host of faint stars which escape ordinary attention. These faint K stars may well outnumber the more brilliant B stars a hundred-fold, even when we only include stars to absolute magnitude 7.0.

If, as is probably the case, the giant stars are more massive than the dwarf, the proportion of intrinsically faint stars must be still further increased.

This result is, of course, not new, and it is confirmed by many facts of common knowledge. It is as old as the recognition that proper motion is a better index than apparent magnitude for nearness to our system, and that amongst stars with large proper motion late type stars predominate. As special stars which have attracted attention we might mention Krueger 60 and Barnard's proper motion star. Both are classed as Mb stars, their apparent magnitudes are 9.2 and 9.7, and if we adopt their well-determined trigonometric parallaxes their absolute magnitudes are 11.2 and 13.3 respectively. We can only expect to discover such stars as these when they are within 10 parsecs of the solar system.

The attention of observers should again be drawn to stars of late spectral type, especially those with large proper motion. In particular we would suggest that such stars, even when faint, should be examined for duplicity, for amongst them the relative motion should be comparatively rapid.

The Stellar Universe.

The results obtained in this paper from double stars agree closely with Russell's view of the sidereal universe, and disclose no facts hostile to his theory. We may summarise the position as follows, drawing from facts outside the scope of this paper.

There is in the neighbourhood of the sun at least one double star to every 100 cubic parsecs, even when we limit ourselves to stars as bright as 8^m.0 absolute. The range in luminosity is very great. There are stars brighter than -2^m.0 absolute, although such stars are unusual. So far as we can tell, the number of stars of different absolute magnitude increases steadily and rapidly with the faintness. We cannot set a limit to the faintest possible star, but there are certainly some, probably many, stars as faint as 13^m.0 absolute.

The range in stellar masses is small compared with that in the luminosities. The more luminous stars may be ten times as massive as the sun, with a few exceptional and still more massive stars. The great majority of the stars ordinarily observed may have a mass approximately equal to that of the sun. Intermingled with these stars are large numbers of intrinsically faint stars, probably considerably less massive, say of the order of half or even a tenth of the sun's mass.

The most brilliant stars are of spectral type B. These are extremely rare, and probably are not so numerous as one in a hundred, even amongst stars brighter than $7^{\text{m}}.0$ absolute. They may be many times less numerous than this estimate. As we pass along the spectral series A, F, G, K, M the stars become on the average fainter and much more numerous. There are, however, some stars of spectral types K and M, and quite possibly also G, which rival the B stars in brightness, but the great majority of K and M stars are much fainter.

Russell based his theory of stellar evolution on various astronomical results and on arguments drawn from discoveries in physical science. With regard to the life-history of stars, he says: "The hottest stars—those of Class B—are on the average decidedly more massive than those of any other spectral type. On the present theory this is no mere chance, but great mass is the necessary condition—one might almost say the cause—of the attainment of unusually high temperature. Only these stars would pass through the whole series of the spectral classes, from M to B and back again, in the course of their evolution. Less massive bodies would not reach a higher temperature than that corresponding to a spectrum of Class A; those still less massive would not get above Class F, and so on. This steady addition of stars of smaller and smaller mass as we proceed down the spectral series would cause a steady diminution of average masses with 'advancing' type in the case of the giants as well as that of the dwarfs. . . . It is now easy to see why there is no evidence of the existence of luminous stars of mass less than one-tenth that of the sun. Smaller bodies do not rise, even at maximum, to a temperature high enough to enable them to shine perceptibly (from the stellar standpoint), and hence we do not see them."

Reasoning in the light of this theory, we conclude that the small number of B stars is evidence of the comparative rareness of masses sufficiently large for such high temperatures to be reached, or of the comparatively short duration of this stage. On the other hand, the great number of faint stars of the later type is evidence of the large number of smaller masses, or of the stability of this stage of stellar existence. Even the presence of stars of intermediate brilliancy in the G5 and K0 classes can be easily explained on the theory. We may consider them as derived from masses only slightly less than the typical F and G stars, and their comparative brilliance has enabled them to get into our list, although they are present in space in comparatively small numbers. The brightest K0 star within 20 parsecs is only $4^{\text{m}}.6$ and the next $5^{\text{m}}.9$ absolute.

TABLE I.

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
21	A3	6'22	2'0	"014	4570	Ao	6'35	2'4	"016
104	Go	7'70	3'3	'013	4771	F8	3'48	0'8	'030
314	Go	5'24	3'8	'053	4923	F8	4'87	3'8	'062
335	Ko	5'71	4'6	'061	5005	Ko	7'26	5'8	'051
374	F8	7'61	4'5	'024	5103	Go	5'52	2'8	'028
426	F8	3'64	4'6	'152	5223	A2	4'54	-0'2	'011
479	Ao	5'76	1'6	'014	5235	A2	5'16	1'5	'019
482	Ko	5'60	3'0	'031	5365	Fo	6'56	3'6	'026
1015	Go	6'18	3'9	'035	5388	Ko	$\begin{cases} 2'61 \\ 3'80 \end{cases}$	$\begin{cases} -0'1 \\ +1'1 \end{cases}$	'029
1036	A3	4'61	2'3	'034	5515	F5	7'9	3'9	'016
1070	$\begin{cases} Ko \\ Ao \end{cases}$	$\begin{cases} 2'28 \\ 5'08 \end{cases}$	$\begin{cases} -1'3 \\ 1'5 \end{cases}$	'019	5734	Go	$\begin{cases} 4'87 \\ 4'41 \end{cases}$	$\begin{cases} 5'4 \\ 5'0 \end{cases}$	'130
1144	Fo	6'03	3'1	'025	5765	F5	4'03	3'0	'062
1471	Fo	5'32	0'8	'012	5805	F5	6'99	2'9	'015
1623	F8	8'1	3'8	'014	5811	F5	5'47	3'2	'036
1761	A2	5'92	0'7	'009	5951	F8	6'78	3'6	'023
2007	G5	7'18	5'8	'053	6028	F5	6'81	2'1	'012
2093	F8	7'40	3'5	'017	6158	A5	6'31	2'3	'016
2109	G5	4'48	4'9	'119	6243	Fo	$\begin{cases} 3'65 \\ 3'68 \end{cases}$	$\begin{cases} 3'5 \\ 3'5 \end{cases}$	'092
2134	Go	6'86	3'6	'023	6296	Ko	5'10	2'9	'036
2154	Go	7'09	4'8	'035	6406	F5	$\begin{cases} 5'22 \\ 5'22 \end{cases}$	$\begin{cases} 4'2 \\ 4'2 \end{cases}$	'061
2187	Go	7'72	4'2	'019	6524	A5	6'80	3'2	'019
2381	F5	6'96	3'8	'023	6530	Ko	7'36	5'3	'038
2383	F5	6'70	3'7	'025	6566	Fo	4'92	2'0	'026
2535	Fop	5'47	2'8	'029	6578	F2	5'54	2'3	'022
3474	Go	6'89	3'6	'022	6641	K2	7'26	6'2	'060
3559	A2	4'89	1'5	'021	6711	F5	7'8	4'0	'017
3596	Ao	-1'58	1'7	'446	6780	F8	7'04	3'9	'024
3876	F5	6'44	3'2	'022	6842	Ao	$\begin{cases} 6'64 \\ 5'11 \end{cases}$	$\begin{cases} 2'6 \\ 1'1 \end{cases}$	'016
4122	Ao	$\begin{cases} 2'85 \\ 1'99 \end{cases}$	$\begin{cases} 2'7 \\ 1'8 \end{cases}$	'093	6955	A2	$\begin{cases} 4'83 \\ 4'43 \end{cases}$	$\begin{cases} 1'2 \\ 0'8 \end{cases}$	'019
4187	F5	0'48	2'7	'280	6999	F8	7'17	3'8	'021
4310	Go	5'34	4'5	'067	7001	F5	7'24	2'8	'013
4355	F8	6'44	2'7	'018	7034	G5	4'64	5'3	'134
4414	G5	7'9	5'5	'033					
4477	Go	$\begin{cases} 6'26 \\ 6'02 \\ 5'56 \end{cases}$	$\begin{cases} 4'5 \\ 4'2 \\ 3'8 \end{cases}$	'044					

TABLE I.—*continued.*

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
7120	G0	4.86	4.4	"082	8966	A2	6.31	1.5	"011
7251	G0	{ 5.58 6.08	{ 4.4 4.9	'059	9114	G5	8.0	4.6	'021
7259	K0	6.66	3.9	'028	9319	F8	7.3	3.6	'018
7332	K0	6.8	5.2	'047	9605	A	2.97	0.8	'036
7368	A0	3.93	1.3	029	9643	A2	4.95	2.3	'030
7416	F2	6.60	2.4	'014	9650	F5	6.52	2.8	'018
7487	F8	{ 5.07 4.77	{ 3.4 3.0	'045	9979	G5	7.1	3.6	'020
7561	K5	8.5	6.3	'036	10363	F5	3.72	1.9	'043
7563	F5	{ 5.76 6.66	{ 4.6 5.5	'059	10533	B5	4.47	0.9	'020
7642	G5	7.0	5.3	'045	10559	F	5.99	2.4	'019
7649	A0	3.85	1.8	'038	10643	F5	5.29	2.1	'023
7717	G0	3.00	3.0	'101	10732	K5	{ 5.57 6.28	{ 7.8 8.5	'276
7748	K5	7.8	5.1	'030	10829	F5	4.61	3.8	'067
7783	F5	6.81	3.3	'020	10846	F0	3.82	2.5	'055
7878	F5	{ 5.83 5.80	{ 4.1 4.1	'045	11222	F5	4.27	2.6	'046
7929	K5	5.89	6.3	'123	11743	F5	{ 4.59 4.42	{ 2.8 2.7	'045
7936	...	...	...	'010	11761	Ma	9.2	10.2	'157
8038	G	5.34	4.4	'066	11763	F	5.47	2.1	'021
8099	F	5.31	4.1	'057	12196	G5	4.56	1.6	'026
8162	{ G5 Mb	{ 3.48 9.7	{ 3.1 9.3	'084	12290	G5	8.2	5.6	'030
8303	F	{ 6.04 5.34	{ 3.3 2.6	'028	12404	F5	6.82	3.0	'018
8340	{ K0 K6	{ 4.07 6.05	{ 5.4 7.4	'183	12696	...	...	...	'034
8353	...	...	...	'030	12701	G0	5.85	5.2	'074
8372	F8	5.21	4.2	'062	12755	G5	6.10	4.7	'051
8380	F	5.67	2.4	'022	1 ^h , 37	G5	{ 6.00 6.03	6.2 6.2	'110
8679	F8	6.47	3.6	'026	9, 40	F5	3.64	2.7	'065
8933	G0	5.21	4.3	'064	12, 61	A0	2.38	0.5	'043
8965	A2	2.71	1.6	'059	14, 59	{ G0 K5	{ 0.33 1.70	{ 4.7 6.1	'762
					15, 55	B3	2.95	0.2	'028
					18, 113	F8	{ 5.01 5.01	{ 4.2 4.2	'068

TABLE II.

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
70	F5	6.30	0.7	.008	1459	B9	6.42	1.2	.009
260	B8	4.88	0.5	.008	1501	K0	7.62	0.8	.004
322	F8	8.6	6.1	.031	1508	A3	6.68	1.8	.011
374	F8	7.61	5.3	.035	1512	A2	{ 5.55 5.25	{ 2.1 1.8	.020
431	G0	7.62	2.0	.008	1517	F0	7.38	1.9	.008
440	F5	8.02	4.2	.017	1559	B8	{ 6.11 6.11	{ -1.7 -1.7	.003
456	...	...	...	.014	1584	F0	7.8	3.4	.014
479	A0	5.76	2.0	.018	1594	G0	7.43	3.0	.013
489	B9	5.54	1.0	.012	1598	G0	8.1	3.1	.010
508	A0	6.41	1.7	.011	1623	F8	8.1	4.7	.021
600	B8	4.28	-0.9	.009	1639	G0	7.30	4.2	.024
614	F5	6.88	2.9	.016	1678	G0	8.3	4.3	.016
707	F5	6.01	2.1	.016	1774	F0	6.83	1.6	.009
714	F0	6.89	0.8	.006	1799	F5	6.85	3.8	.024
830	F8	6.94	3.0	.016	2007	G5	7.18	5.3	.043
887	A2	6.14	3.3	.026	2027	G5	7.10	5.5	.047
898	F5	8.1	4.0	.015	2034	F8	8.4	3.1	.009
900	K0	8.9	5.0	.017	2041	F8	7.47	4.6	.026
926	F8	8.1	3.9	.014	2050	G0	9.0	3.9	.010
941	A2	5.99	1.8	.015	2115	F5	7.48	2.2	.009
946	F2	8.7	5.0	.018	2146	B9	5.98	-0.4	.005
981	F0	7.67	3.3	.013	2161	A2	6.90	3.8	.024
992	F5	8.3	3.0	.009	2163	F5	5.81	4.4	.053
1002	F2	7.27	1.8	.008	2172	A2	5.06	0.2	.011
1039	A3	7.8	2.1	.007	2200	G0	7.72	4.8	.026
1061	A2p	{ 5.23 4.33	{ 3.3 2.4	.042	2255	F2	6.81	2.4	.013
1074	F5	5.68	3.0	.028	2270	A2	7.4	1.6	.007
1137	G0	5.20	1.3	.017	2272	G0	8.4	5.0	.021
1212	...	...	...	.013	2279	F0	5.44	2.0	.020
1235	B8	7.11	2.6	.012	2284	F0	6.49	3.4	.024
1346	K0	7.05	2.2	.010	2307	F8	7.8	4.6	.023
1365	F5	8.1	4.6	.020	2336	G5	8.16	6.2	.041
1386	F5	5.73	4.1	.046	2443	F5	8.2	4.3	.016
1405	F0	7.06	3.3	.018	2445	F5	6.00	4.2	.045
1420	F2	7.9	4.3	.019	2446	G	8.82	7.5	.055
1427	G0	6.95	5.1	.043	2464	G5	7.95	3.9	.016
1445	A2	7.15	3.4	.018					

TABLE II.—*continued.*

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
2466	A5	8.8	3.6	"009	3423	A3	6.82	3.5	"022
2509	A2	6.46	2.2	"014	3460	F5	7.44	4.1	"021
2535	Fop	5.47	3.3	"037	3474	G0	6.89	3.5	"021
2544	A3	5.97	1.6	"013	3484	G5	8.1	3.7	"013
2588	{ A2 G	6.25	0.5	"007	3515	F2	6.86	2.1	"011
2609	F5	8.2	3.5	"012	3542	Oe5	4.68	0.3	"013
2613	B3	7.5	2.9	"012	3559	A2	4.89	2.1	"027
2706	F5	6.11	2.8	"022	3601	A0	6.16	1.8	"014
2731	B9	7.3	3.4	"017	3615	A2	6.90	1.9	"010
2751	A0	5.44	2.2	"022	3625	{ F5 A2	5.44	1.0	"013
2780	B3	4.32	0.7	"019	3678	G0	4.54	0.3	"014
2812	F5	8.0	3.0	"010	3689	G0	8.1	4.3	"018
2826	F8	7.10	2.9	"014	3692	F0	4.70	3.5	"058
2835	F8	6.74	4.9	"028	3710	A0	7.59	3.8	"017
2845	B8	5.70	1.3	"013	3728	A5	8.5	4.3	"015
2857	A2	5.49	0.3	"009	3755	...	...	...	"013
2866	B9	7.33	1.8	"008	3793	A2	6.19	2.8	"021
2883	B0	3.78	-1.1	"010	3876	F5	6.44	3.5	"026
2902	B0	{ 2.05 4.21	{ -1.9 0.2	"016	3949	G0	6.99	3.9	"024
2975	F8	7.5	2.2	"009	3970	F0	3.51	2.1	"053
2976	A3	5.27	-0.3	"008	3972	A2	8.3	4.2	"015
2977	A5	7.76	4.6	"023	4004	...	...	...	"029
3003	B8	6.82	1.4	"008	4016	B9	8.0	1.9	"006
3035	A5	7.16	0.6	"005	4065	F5	8.0	3.8	"014
3065	B9	7.81	3.2	"012	4098	F8	5.94	4.0	"041
3085	B9	8.5	4.8	"018	4193	A0	5.81	0.9	"010
3146	A0	7.3	1.3	"006	4312	A2	6.99	2.0	"010
3148	A2	7.02	2.5	"012	4333	F0	7.15	3.2	"016
3174	A0	8.3	3.7	"012	4377	K0	6.42	2.6	"017
3191	B9	6.68	0.8	"007	4402	G5	8.3	5.4	"026
3277	A2	6.02	0.9	"010	4406	A0	6.61	1.1	"008
3291	A3	7.16	1.8	"009	4414	G5	7.9	7.1	"069
3379	A0	7.77	3.1	"011	4421	B9	6.16	1.5	"012
3402	B2p	{ 4.73 5.22 5.60	{ -3 +2 +6	"010	4452	F2	6.74	4.0	"028
					4467	A2	8.8	4.5	"014
					4492	F8	7.30	4.3	"024
					4502	F8	8.0	3.6	"013

TABLE II.—*continued.*

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
4526	G5	9'0	3'0	"006	5445	F8	7'6	2'5	"010
4531	...	...	...	'012	5448	G5	8'4	5'0	'021
4570	A0	6'35	2'2	'014	5508	F2	7'6	3'8	'017
4601	A2	{ 6'30 6'32	{ 2'1 2'1	'014	5515	F5	7'9	4'1	'017
4602	{ A3 G	{ 7'10 7'64	{ 4'6 5'1	'032	5527	A2	7'6	1'8	'007
4771	F8	3'48	2'4	'060	5533	...	...	...	'010
4777	F5	8'6	2'6	'006	5558	F0	8'2	1'4	'004
4808	...	...	...	'012	5560	A3	6'85	2'5	'014
4828	A2	5'60	1'0	'012	5572	A2	6'49	2'3	'015
4839	K0	5'60	0'6	'010	5603	A0	{ 4'51 6'30	{ 1'5 3'3	'025
4890	K5	8'6	6'6	'040	5633	F8	7'28	3'7	'019
4901	A2	7'01	2'1	'011	5659	F0	7'11	2'2	'010
4972	{ K2 K2	{ 8'1 8'1	{ 9'7 9'7	'209	5679	F5	7'34	4'0	'022
5004	F5	6'54	3'4	'024	5694	...	...	...	'019
5011	A5	5'76	-0'1	'007	5707	G0	6'94	2'5	'013
5014	A2	3'82	-0'4	'014	5739	G0	6'65	3'2	'020
5018	F5	8'6	3'8	'011	5757	G5	8'1	6'3	'044
5030	F2	5'86	3'5	'034	5765	F5	4'03	2'8	'057
5056	F5	8'1	3'5	'012	5793	A2	5'26	2'9	'034
5071	F5	6'81	3'5	'022	5841	A3	5'82	1'6	'014
5094	F5	6'71	2'8	'017	5858	G0	6'34	5'2	'060
5171	G5	6'96	4'1	'027	5859	F8	8'2	4'8	'021
5224	F2	7'81	1'8	'006	5926	A5	5'90	3'4	'031
5233	K0	8'1	5'0	'024	5970	F2	6'55	2'0	'012
5281	G5	8'17	2'0	'006	6030	...	...	...	'013
5349	G5	8'2	3'6	'012	6053	A3	6'82	3'0	'017
5365	F0	6'56	2'8	'018	6076	F5	8'50	2'7	'007
5385	K0	8'8	5'8	'026	6090	G5	7'42	5'8	'048
5388	K0	{ 2'61 3'80	{ 0'3 1'5	'035	6097	...	...	...	'034
5409	G5	7'37	5'7	'047	6174	K2	8'6	6'0	'030
5421	G5	8'2	4'6	'019	6187	F2	7'9	3'7	'014
5426	F0	7'7	2'6	'010	6211	F8	7'72	4'6	'023
5433	G5	8'7	5'9	'028	6216	G5	8'3	4'7	'019
5437	K0	7'22	2'5	'012	6222	F2	7'71	1'9	'007
					6296	K0	5'10	2'5	'030
					6312	F5	6'56	1'5	'010
					6329	G5	7'82	1'3	'005

TABLE II.—*continued.*

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
6348	Fo	4.89	3.2	"047	7013	F8	6.72	2.6	"016
6358	F5	8.1	2.7	'008	7040	Ko	8.0	4.5	'020
6367	Fo	6.51	0.8	'007	7044	Go	7.78	3.6	'015
6369	...	...	...	'012	7049	Go	6.43	3.6	'027
6373	Fo	8.0	3.8	'014	7119	Go	8.1	2.2	'007
6395	F8	8.2	2.6	'008	7212	G5	8.6	7.9	'072
6415	F8	6.66	3.1	'020	7214	F8	6.55	3.9	'030
6442	Ko	6.55	5.6	'064	7273	F8	7.9	3.2	'012
6455	Ao	6.23	0.6	'007	7276	G5	7.40	4.1	'022
6476	K5	8.86	5.7	'023	7318	Fo	{ 5.16	{ 3.2	'041
6494	F5	7.9	4.2	'018			{ 4.23	{ 2.3	
6500	...	...	...	'030	7352	B8	{ 6.00	{ 2.4	'019
6510	F8	8.8	3.9	'011			{ 5.07	{ 1.5	
6527	Go	8.12	4.9	'023	7367	G5	6.44	0.8	'007
6530	Ko	7.36	5.9	'052	7375	Ko	8.4	4.1	'014
6586	A2	5.65	2.9	'028	7414	Ao	7.57	2.6	'010
6599	Ko	5.62	1.7	'016	7440	F2	6.94	2.3	'012
6619	Go	7.22	3.9	'021	7477	F5	7.02	2.6	'013
6668	F8	6.20	3.8	'033	7490	A3	8.0	3.3	'011
6725	Go	7.39	5.0	'033	7495	F5	6.36	2.4	'016
6746	G5	8.4	4.0	'014	7505	F5	8.5	3.0	'008
6758	F2	7.56	1.5	'006	7551	Ko	6.84	5.1	'045
6764	F2	7.67	2.6	'010	7552	F2	6.37	2.6	'018
6766	Go	8.1	3.0	'010	7554	F5	8.5	3.9	'012
6773	F8	8.4	2.7	'007	7587	{ A5 G	7.86	1.7	'006
6776	K2	8.2	6.1	'038					
6780	F8	7.04	4.8	'035	7619	...	...	...	'011
6832	F8	7.23	4.2	'025	7632	G5	5.64	0.1	'008
6851	F2	6.48	2.8	'018	7634	G5	2.89	0.6	'034
6913	A2	5.90	3.0	'026	7637	A3	6.68	1.2	'008
6948	F2	6.79	0.9	'007	7651	Ao	8.1	2.7	'008
6954	Ao	{ 4.94	{ 1.7	'023	7673	G5	7.17	1.5	'007
		{ 5.81	{ 2.6		7703	Ao	5.64	1.6	'015
6958	F5	7.9	2.4	'008	7739	F2	6.76	0.7	'006
6975	Fo	7.24	2.9	'013	7751	G5	8.9	4.1	'011
6993	{ Ao Ko	{ 5.12	{ 1.5	'019	7759	Go	7.27	3.8	'020
		{ 2.70	{ -0.9		7777	Ao	5.47	0.2	'009
6997	Go	7.9	4.1	'017	7778	F8	6.77	2.1	'012

TABLE II.—continued.

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
7779	A2p	4'86	2'6	"035	8337	...	...	...	"005
7817	Go	8'5	4'1	'013	8368	...	...	...	'012
7831	...	...	...	'011	8370	A2	7'40	1'3	'006
7834	Fo	6'44	2'5	'016	8380	F2	5'67	2'8	'026
7837	Ao	6'24	2'7	'020	8384	F5	7'6	1'8	'007
7863	Go	8'34	5'3	'025	8398	{ F2 Ao	6'14	0'8	'009
7878	F5	{ 5'83 5'80	{ 4'8 4'8	'062	8421	A2	8'2	2'1	'006
7885	A2	2'63	-1'3	'016	8433	F2	7'88	4'5	'021
7898	Ko	7'16	5'9	'057	8485	F5	6'51	4'1	'033
7914	Mb	3'48	0'2	'022	8507	G5	7'13	5'2	'041
7936	Mb	5'39	0'9	'012	8543	A3	6'90	0'5	'005
7955	...	...	...	'009	8548	Ao	6'20	1'6	'012
7965	Ko	8'8	5'2	'019	8574	A2	4'85	1'9	'026
8003	Ao	{ 5'47 4'52	{ 1'6 0'6	'017	8575	G5	7'24	1'3	'006
8004	...	...	...	'012	8584	B9	6'82	1'3	'008
8008	...	...	...	'030	8615	B9	7'9	3'4	'013
8017	Fo	7'61	6'4	'057	8622	F5	7'34	2'5	'011
8028	...	...	...	025	8659	A2	7'37	2'1	'009
8055	B8	7'7	2'1	'008	8662	Ko	5'76	1'0	'011
8100	Ao	6'66	0'6	'006	8663	Go	6'17	3'9	'035
8118	F5	7'34	4'1	'023	8751	Go	7'7	3'4	'014
8120	F5	5'58	3'6	'040	8776	Ao	5'72	0'8	'010
8127	A2	6'97	1'2	'007	8861	F8	8'1	1'8	'006
8145	F5	6'83	3'1	'018	8905	Ao	6'83	1'7	'009
8153	Ko	7'9	4'8	'024	8909	Go	7'7	3'7	'016
8163	Ao	5'58	0'4	'009	8930	Ao	7'34	1'5	'007
8167	K2	8'6	7'5	'060	8986	{ G5 G5	{ 8'5 8'5	{ 5'9 5'9	'030
8186	F2	7'7	2'5	'009	8988	G5	7'46	2'6	'011
8203	Go	8'1	3'4	'011	9023	...	...	...	'020
8210	Ko	6'54	1'8	'011	9038	Ko	8'2	4'3	'016
8228	A5	8'1	1'2	'004	9043	Fo	7'10	6'7	'021
8241	A2	6'14	-0'5	'005	9054	Ko	8'8	3'2	'007
8242	G5	8'1	4'7	'021	9056	Ao	8'0	2'7	'009
8321	A3	7'82	2'2	'007	9114	G5	7'51	5'7	'043
8326	...	...	...	'007	9124	Fo	8'3	3'4	'010
8331	F2	7'22	3'2	'016	9155	G5	8'1	3'4	'011

TABLE II.—*continued.*

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
9173	A2	8.1	2.8	.009	10504	Ko	7.04	4.7	.033
9279	F8	8.7	3.5	.009	10519	G5	8.16	3.4	.011
9298	F5	7.9	4.5	.021	10533	B5	4.47	0.5	.016
9318	A	8.5	6.3	.037	10607	G5	8.0	4.4	.019
9381	...	...	...	.032	10608	Go	7.38	3.6	.018
9415	G5	7.20	1.1	.006	10643	F5	5.29	3.1	.037
9450	A3	8.3	3.2	.009	10685	F5	6.50	3.1	.021
9456	Go	7.9	3.1	.011	10690	Fo	7.50	2.7	.011
9459	A	8.6	2.9	.007	10709	Go	8.1	5.3	.027
9500	F2	7.22	2.7	.012	10749	A2	6.68	1.4	.009
9565	Ao	6.72	-0.8	.003	10773	Ao	5.57	1.4	.015
9570	F5	7.30	2.5	.011	10809	F8	8.0	3.7	.014
9502	Ko	8.5	7.2	.056	10841	G5	7.17	1.2	.006
9634	{ F2 A2	5.70	0.1	.008	10871	A2	7.87	3.9	.010
9686	...	...	...	.024	10910	F8	7.9	5.1	.027
9712	F8	7.04	4.3	.028	10922	G5	6.44	3.2	.023
9719	F2	6.45	3.0	.021	11001	F2	6.70	3.6	.023
9724	Ko	3.90	2.8	.059	11042	A5	7.7	3.4	.014
9782	A2	6.48	-0.1	.005	11051	F5	7.11	4.5	.030
9783	A5	7.12	0.8	.005	11125	F5	6.80	3.3	.020
9833	Fo	5.32	0.6	.011	11168	G	8.0	2.6	.008
9921	A5	9.8	4.4	.008	11210	F5	8.0	4.3	.018
9926	F5	6.38	2.4	.016	11214	F5	{ 4.73 6.08	{ 3.9 5.2	.068
9944	Go	8.8	4.6	.014	11246	F2	7.68	2.6	.010
9994	Ao	6.57	-0.3	.004	11346	G5	7.92	4.6	.021
10017	Ao	6.48	2.6	.016	11490	Go	7.58	2.0	.008
10072	F8	8.4	3.3	.010	11556	A2	7.9	2.4	.008
10147	F8	8.8	3.9	.011	11590	Ao	6.60	1.1	.008
10160	F2	8.4	3.8	.012	11599	F5	7.10	2.6	.013
10213	G5	7.67	4.2	.020	11650	F5	8.7	3.9	.011
10281	{ Ao Ao	{ 7.26 7.04	{ 0.0 -0.2	.004	11687	...	...	...	.017
10310	...	...	...	.010	11690	F5	6.13	3.8	.034
10423	B8	5.93	-0.3	.006	11691	Ao	5.85	1.6	.014
10461	F8	8.56	4.4	.015	11715	Go	{ 6.57 6.35	{ 5.7 5.5	.067
10483	Ao	6.70	2.4	.014	11732	F8	9.0	2.7	.006
10487	G	8.5	3.6	.010	11736	Ko	7.19	4.0	.023

TABLE II.—*continued.*

B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.	B.G.C.	Spec. Type.	Mag.	Abs. Mag.	Hyp. Par.
11741	Ko	8·3	5·9	·033	12228	F2	8·8	4·5	·014
11743	F2	{ 4·59 4·42	{ 3·7 3·5	·066	12317	K5	8·6	7·2	·054
11763	F5	5·47	2·5	·026	12432	K2	5·21	1·1	·015
11908	Go	8·3	5·5	·027	12468	B9	5·86	0·6	·009
11943	...	...	...	·032	12510	A0	7·25	2·9	·014
11968	Go	6·75	4·3	·032	12531	F2	8·00	3·5	·012
11979	B9	7·26	1·4	·007	12532	Ko	4·98	0·9	·015
12036	A0	5·62	3·0	·030	12562	B3	5·84	1·3	·012
12065	A3	6·46	2·5	·016	12563	G	7·8	3·2	·012
12094	F0	5·79	2·4	·021	12675	F8	{ 6·58 6·58	{ 5·0 5·0	·049
12104	F5	8·6	4·0	·012	12709	Go	7·7	4·9	·028
12125	A2	5·08	0·7	·013	12740	K2	8·62	8·6	·098
12178	F2	7·47	0·4	·004	12750	Ko	8·8	5·8	·025

TABLE III.

Unit 0·001.

B.G.C.	Hyp. Par.	Spec. Par.	Abs. Trig. Par.	Wt.	B.G.C.	Hyp. Par.	Spec. Par.	Abs. Trig. Par.	Wt.
314	53	...	52	1	4477	44	43	54	2
335	61	66	...	...	4771	30	40	25	Spec.
426	152	178	187	5	5005	51	83	67	3
1015	34	...	46	1	5388	29	...	24	1
1036	34	...	2	1	5734	130	148	158	3
1070	19	...	8	2	5805	15	...	42	1
1144	24	...	73	1	5811	36	...	55	1
1471	12	40	13	2	6158	16	...	24	1
1623	14	...	30	1	6243	92	78	68	3
2109	119	200	182	4	6406	61	...	65	2
2381	23	33	24	2	6524	19	...	71	1
2383	25	27	7	1	6578	22	...	5	3
2535	29	...	20	1	6842	16	...	18	1
3474	22	...	38	2	7001	13	...	24	1
3596	446	...	376	1	7034	134	152	193	2
4122	93	100	78	3	7251	59	69	83	2
4187	280	331	305	5	7259	28	52	47	1
4310	67	...	125	1	7332	47	...	44	1
4414	32	...	86	1	7368	29	...	30	3

TABLE III.—*continued.*

B.G.C.	Hyp. Par.	Spec. Par.	Abs. Trig. Par.	Wt.	B.G.C.	Hyp. Par.	Spec. Par.	Abs. Trig. Par.	Wt.
7487	45	...	54	1	12755	51	38	34	1
7563	59	49	46	1	14 ^b , 59	762	...	759	10
7642	45	110	(88)	(1)					
7649	38	...	5	3	322	31	...	27	1
7717	101	66	102	4	600	9	...	8	1
7783	20	...	22	3	1623	21	...	30	1
7929	123	...	170	1	2279	20	...	25	1
8038	66	...	63	2	2535	37	...	20	1
8099	57	76	82	2	2902	16	...	16	1
8162	84	92	95	4	3291	8	...	5	1
8340	183	204	175	5	3474	21	...	38	2
8372	62	105	50	3	3970	53	...	59	1
8679	26	...	34	1	4414	69	...	86	1
8933	64	79	116	2	4771	60	40	25	Spec.
9114	21	...	22	2	4972	209	160	152	5
9319	18	...	17	1	5388	35	...	2	1
9605	36	...	53	1	5858	60	35	38	1
9650	18	...	19	1	6993	19	21	14	1
9979	20	...	47	1	7634	34	40	19	1
10363	43	38	26	2	7914	22	14	13	1
10643	23	38	24	1	9114	43	...	22	2
10732	276	295	311	16	9724	59	72	71	2
10829	67	63	67	Spec.	10504	33	...	18	1
10846	55	42	53	3	10643	37	38	24	2
11222	46	66	34	4	11125	20	48	17	1
11761	157	251	261	4	11214	68	...	45	1
12196	26	...	16	1	10690	34	48	60	1
12290	30	...	6	2	12740	98	120	98	3
12701	74	...	94	3					

Stellar Parallaxes determined at the Royal Observatory, Greenwich.

(Communicated by the Astronomer Royal.)

This list is a second instalment of the results obtained with the 26-inch telescope, the first of which was published in the *Monthly Notices* for June 1915.

Up to 1917, when the work was interrupted by the war, observations had been carried out on the lines suggested by Professor Kapteyn, viz. by making exposures at two different epochs on the same plate. This plan has a good deal in its favour, but at the same time has decided disadvantages in an uncertain climate, and after careful consideration it was decided, on the resumption of work in 1919, to discontinue this method, at least for a time, and to develop the plates as exposed.

Instead of a direct comparison of photographs on the same plate, they must now be compared by some other method in the micrometer. Comparison by projection has the disadvantage that errors of the slides, and more particularly temperature effects, are introduced. A plan that suggested itself was the taking of one photograph of the field through the glass of the reversed plate. This plate may be placed film to film with each plate of the series successively and used as a scale of reference. This auxiliary plate is adjusted on the photograph so that the images on the two plates are brought within 0.5 mm. of one another. Each photograph is measured with the auxiliary plate uppermost. Any aberration arising from the glass of the auxiliary plate would affect equally every photograph compared.

This method proved satisfactory. It was evident, however, that there would be a slight increase in the accidental error of measurement arising from bisection of the images on the auxiliary plate, which might be reduced if these could be made more definite. This led to the substitution of a ruled scale plate to be used in an identical manner. On a polished glass plate, short straight lines were made with a diamond in the measured positions of the selected comparison stars. These proved excellent points of reference, and although with the rough ruling machine experimentally constructed for the purpose the division errors are somewhat large, this is of little consequence, as they disappear in the comparison of plate with plate. As this scale and the photograph under measurement are firmly clipped together in the micrometer, scale and photograph must respond together to any changes of temperature, and of course the slides of the machine do not enter with this method of measurement, any more than when a printed *réseau* is employed.

The results depend on photographs taken between 1913 and 1920. Those before 1918 are "Kapteyn" plates, and those since that date are single. All have been compared with the scale plates, and the morning and evening exposures on the Kapteyn

plates separately compared. Each plate leads to an equation of the form $t\mu + f\pi + c = R$. These are solved by least squares.

The residuals have not yet been critically analysed, but a first inspection seems to indicate that there is a very small plate error. By comparing all the photographs taken over an extended period with a common standard, the systematic error at any particular epoch is likely to become an accidental error, and as the observations extend over several years, it is hoped that though the discordances from these sources increase the probable error, yet it becomes an approximation to the real probable error.

The P.E. has been calculated by the formulæ

$$r = 0.8453 \times \frac{[v]}{\sqrt{m(m-\mu)}} \times \frac{1}{\sqrt{w}}$$

and

$$r = 0.6745 \times \sqrt{\frac{[v \cdot v]}{m-\mu}} \times \frac{1}{\sqrt{w}},$$

and the larger value given is printed in the table.

Eight comparison stars are used of mean magnitude 11-12, to which magnitude the parallax star is reduced by means of the rotating sector.

Thirteen of the stars have already appeared in the first published list. The values given here are not new determinations, but revised results with additional material.

In the column "Proper Motion" the first is derived from meridian observations, the second, in R.A. only, from the parallax plates.

No.	Name and B.D. No.	Mag. Visual Photog.	Spectral Type.	R.A. Dec. 1900.	Proper Motion.		Parallax.	P.E.	No. of Plates.
					R.A.	Dec.			
1	Carr. 113	8.8	G5	h m s 0 49 12	+ "297	+ "106	+ "000	± "009	12
	86° 14	9.1		+ 86° 47'	+ '338				
2	Lal. 1985	6.7	G0	1 4 6	+ '229	+ '025	+ '014	± '007	12
	67° 98	7.0		+ 67° 15'	+ '223				
3	71° 190	8.9	F8	3 8 17	+ '213	- '276	+ '012	± '007	21
		9.1		+ 71° 55'	+ '232				
4	O.A. 4198	9.4		3 46 19	+ '204	- '150	- '007	± '006	14
	69° 230	10.0		+ 69° 33'	+ '194				
5	Groomb. 745	8.3	K5	3 48 24	+ '365	- '506	+ '077	± '007	15
	75° 154	9.0		+ 75° 53'	+ '332				
6	Groomb. 762	7.3	F8	3 54 58	+ '189	- '297	+ '020	± '005	10
	74° 184	7.4		+ 74° 54'	+ '172				
7	Groomb. 775	8.1	G5	3 59 15	+ '099	- '283	+ '056	± '008	11
	69° 238	8.3		+ 69° 17'	+ '066				

No.	Name and B.D. No.	Mag. Visual Photog.	Spectral Type.	R.A. Dec. 1900°0.	Proper Motion.		Parallax.	P.E.	No. of Plates.
					R.A.	Dec.			
8	Lal. F. 635	8.2	G5	h m s 4 2 5	+ "055	- "235	+ "031	± "008	16
	75° 166	9.1		+76° 2'	+ '022				
9	Groomb. 807	7.8	G5	4 17 50	+ '210	- '122	+ '018	± '009	13
	77° 162	8.1		+77° 24'	+ '204				
10	O.A. 5173	8.6	Go	4 44 7	+ '138	- '278	+ '015	± '007	14
	70° 327	8.9		70° 28'	+ '150				
11	Lal. 9884	7.7	F8	5 22 10	+ '087	- '258	+ '009	± '008	16
	78° 193	7.9		+78° 18'	+ '053				
12	O.A. 6352	8.8	Go	5 52 28	+ '044	- '200	+ '008	± '007	13
	64° 557	8.8		+64° 58'	+ '028				
13	Lal. 11206	8.7	G5	5 55 35	+ '034	- '370	+ '020	± '009	18
	67° 410	8.6		+67° 39'	+ '052				
14	70° 395	7.6	G5	6 4 32	+ '006	- '443	+ '040	± '007	14
	7.8			+70° 49'	- '001				
15	O.A. 6657	8.5	Go	6 10 24	+ '025	- '300	+ '031	± '010	15
	65° 523	8.9		+65° 33'	+ '019				
16	P. VI. 75	5.7	F8	6 29 10	- '069	- '616	+ '034	± '009	14
	79° 212	5.7		+79° 40'	- '075				
7	Carr. 953	8.5	G5	6 41 7	+ '012	- '235	+ '024	± '007	16
	83° 172	9.1		+83° 45'	+ '027				
18	Lal. F. 52 (A)	6.8	Go	6 50 46	- '093	- '308	+ '010	± '010	21
	75° 281	7.3		+75° 22'	- '082				
19	Do. (B)	7.8	Go	6 50 47	- '093	- '308	- '010	± '010	14
	8.8			+75° 23'	- '074				
20	O.A. 7699	9.1	G5	7 11 4	- '068	- '300	- '004	± '007	14
	65° 566	9.1		+65° 37'	- '035				
21	O.A. 7908	8.3	G5	7 23 47	+ '072	+ '305	+ '014	± '008	16
	73° 380	8.9		+73° 29'	+ '082				
22	Lal. F. 1265	8.5	G5	8 8 42	- '076	- '278	+ '003	± '008	14
	73° 406	8.5		+73° 39'	- '061				
23	Lal. F. 1266	8.5	G5	8 8 47	- '289	- '494	+ '012	± '007	14
	73° 407	8.7		+73° 44'	- '323				
24	Carr. 1196	9.0		8 21 4	'071	- '210	+ '019	± '007	12
	85° 127	9.9		+85° 3'	- '110				

No.	Name and B.D. No.	Mag. Visual Photog.	Spectral Type.	R.A. Dec. 1900'0.	Proper Motion.		Parallax.	P.E.	No. of Plates.
					R.A.	Dec.			
25	Lal. F. 1384 (A)	7.5	K2	^h 8 ^m 46 ^s 0 +71° 11'	-1''343 -1'296	-''355	+''088	±''006	16
	71° 482	9.3							
26	Do. (B)	7.6	K2	8 46 1 +71° 11'	-1'347 -1'337	- '355	+ '085	± 009	16
	9.6								
					Mean		+ '087	± '006	16
27	Groomb. 1697	6.1	G5	10 46 40 +70° 23'	- '394 - '416	- '079	+ '040	± '010	14
	70° 634	7.0							
28	70° 639	9.5 11.6		10 51 1 +70° 8'	- '630 - '584	+ '058	+ '052	± '010	14
29	Lal. F. 2 137	8.2	G0	10 56 39 +81° 35'	- '217 - '223	- '050	+ '004	± '007	16
	81° 359	8.7							
30	O.A. 11381	8.3	G5	10 58 58 +66° 21'	- '181 - '208	- '150	+ '019	± '011	13
	66° 696	8.9							
31	Lal. F. 1800	7.1	G0	11 2 12 +82° 17'	- '113 - '050	- '182	+ '009	± '010	10
	82° 325	7.6							
32	79° 354	9.5 10.8		11 6 4 +79° 7'	... + '012	...	- '004	± '006	12
33	Lal. F. 1831	7.2	K5	11 8 39 +74° 1'	- '417 - '347	+ '130	+ '079	± '009	13
	74° 456	8.2							
34	Lal. 21927	7.2	F8	11 28 24 +65° 48'	- '055 - '095	- '230	+ '030	± '006	18
	66° 724	7.5							
35	77° 444	9.5 11.5		11 44 2 +76° 58'	... + '005	...	+ '008	± '009	15
36	Carr. 1762	8.8	G5	11 47 27 +86° 47'	- '240 - '212	+ '247	+ '022	± '007	12
	87° 99	8.6							
37	Lal. 22845	8.4	G5	12 5 33 +66° 13'	- '308 - '270	- '030	- '002	± '008	14
	66° 748	8.8							
38	Groomb. 1866	8.2	F8	12 11 52 +64° 11'	- '277 - '270	+ '073	+ '012	± '011	17
	64° 887	8.5							
39	Brad. 1656	6.4	F2	12 13 56 +87° 0'	+ '221 + '222	- '009	+ '031	± '010	26
	87° 107	6.5							
40	Rad. 2897	8.0	F8	12 36 2 +69° 1'	- '455 - '441	+ '060	+ '008	± '012	14
	69° 671	8.0							

No.	Name and B.D. No.	Mag. Visual Photog.	Spectral Type.	R.A. Dec. 1900°0.	Proper Motion.		Parallax.	P.E.	No. of Plates.
					R.A.	Dec.°			
41	84° 284	9.1		h m s 12 36 7	- "201	- "004	+ "006	± "007	18
		9.9		+84° 11'	- '156				
42	Groomb. 1923	7.3	Go	12 37 46	- '232	+ '009	- '002	± '008	18
	84° 286	7.7		+84° 12'	- '244				
43	78° 439	8.9	G5	12 50 13	- '246	+ '032	+ '010	± '009	18
		9.9		+78° 14'	- '234				
44	Groomb. 1947	8.0	Go	12 55 14	- '282	+ '262	+ '030	± '009	17
	69° 681	8.5		+69° 19'	- '303				
45	O.A. 13439	9.2		13 8 45	- '376	+ '092	+ '039	± '011	17
	74° 526	9.2		+74° 23'	- '304				
46	O.A. 13803	8.5	Go	13 31 12	- '156	'000	- '011	± '010	16
	68° 730 (A)	9.5		+68° 17'	- '171				
47	Do. (B)	8.0	Go	13 31 12	- '156	'000	+ '008	± '010	16
		9.1		+68° 17'	- '150				
48	P. XIII. 273	7.6	F 5	13 53 40	- '003	- '282	+ '031	± '008	21
	66° 825	7.9		+65° 51'	- '015				
49	O.A. 23826	9.2		22 13 45	+ '385	- '030	+ '044	± '009	12
	67° 1424	9.9		+67° 50'	+ '378				

Royal Observatory, Greenwich;
1920 November 11.

*Magnitudes of Nova Cygni III., 1920, from Photographs taken with the Astrographic Refractor at the Royal Observatory, Greenwich.**(Communicated by the Astronomer Royal.)*

The following photographic magnitudes of Nova Cygni III. were deduced from plates taken with the astrographic refractor concurrently with those taken by Mr. Luyten with the Thompson equatorial. The aperture of the telescope was reduced to 7 inches, and a diffraction grating was placed in front of the object glass. This gives smaller images, and makes it possible to give longer exposures—thus minimising the errors arising from a want of exact equality in the times of exposure on the nova and the comparison stars.

The magnitudes of the nova were obtained from a comparison of the first diffracted images. The comparison stars used were:—

	Adopted Photo. Mag.
α Urs. Min.	2.71
β Urs. Min.	3.84
γ Urs. Min.	3.35

The plates were measured by comparing the diffracted images with a scale of images graduated in size, the interval between successive scale images being estimated to tenths. In plotting the magnitude curve a small correction was applied to the adopted photographic magnitudes of the comparison stars in order to reduce them to the same altitude as the pole. A correction of $+0^m.14$ has been applied to the observed magnitude of the nova for a similar reason.

Date.	G.M.T.	Magnitude.
1920	h m	
Aug. 22	10 10	3.21
	26 9 23	3.46
	26 10 2	3.26
	27 10 19	3.53
	28 9 51	3.99
	29 8 29	3.77

The plate taken on August 27 was interfered with by cloud, and some of the exposures on the comparison stars were rejected in consequence. The agreement with the magnitudes found by Mr. Luyten is satisfactory except on August 28. It may be noted that the weather was not generally very favourable for making photographic comparisons of different parts of the sky.

Spectroscopic and Magnitude Observations of Nova Cygni III., 1920.

By Major William J. S. Lockyer, M.A., Ph.D., and D. L. Edwards, D.I.C., A.R.C.S. (Plate 1.)

General.

On the afternoon of August 21 a telegram was received at the Hill Observatory, Salcombe Regis, from Brussels, informing us of the fact that Mr. Denning had discovered a new star in Cygnus, of magnitude about 3.5, and giving its position. That evening was cloudy, so observations could not be made until the evening of the 22nd. Since that date a large number of photographs of the spectra have been taken and determinations of magnitude made. It is the object of the present paper to present some of the first results from a discussion of the observations and photographs obtained.

Instruments Employed.

The spectra were all photographed with the Rusthall telescope, which is a Grubb 12-inch refractor having an objective prism of 12 inches aperture and 20 degrees angle. The scale of the spectra is such that 21.4 mm. represent the distance between H_{β} and H_{δ} . The width of the spectra was made by giving a rate to the driving clock, and this width was gradually reduced as the magnitude of the Nova diminished.

The photographic plates used ($4\frac{1}{4} \times 3\frac{1}{4}$) were of two brands. The first always employed were Marion's "Record" plate, having a speed number of H and D 500. These plates have a fine grain, and the extremes of the spectra were generally $\lambda 3790$ to $\lambda 5020$. To extend the spectra more into the red, Ilford Special Rapid Panchromatic plates were occasionally used, but these were not so fast as the first-mentioned.

The determinations of magnitude were made first with a pair of opera-glasses magnifying twice, but later (about September 22) with a pair of field-glasses magnifying eight times. A large number of comparison stars was employed in order to follow the Nova through the various magnitudes it passed.

Magnitude Determinations and the Light Curve.

The magnitudes of the Nova were determined by us quite independently, but we used similar charts for the comparison stars. As the Nova grew fainter the scale of the charts was increased, and fainter comparison stars inserted. In the first instance the magnitudes of the comparison stars were taken from the "Revised Harvard Photometry,"* but later they were extracted from the "Catalogue of 8627 Stars."†

* *Annals of the Astr. Obs. of Harvard College*, 50.

† *Ibid.*, 15.

The following table gives the G.M.T. times of observation, the magnitudes determined by each of us, and the resulting means adopted:—

Date.	W.J.S.L.		D.L.E.		Mean.
	G.M.T.	Mag.	G.M.T.	Mag.	
	h m		h m		
Aug. 22	12 0	2.8	12 0	2.8	2.8
24	16 0	2.2	...	...	2.2
25	11 0	2.2	13 0	2.3	2.25
26	12 0	2.8	12 0	2.7	2.75
28	11 0	3.6	12 0	3.6	3.6
29	12 0	3.8	9 30	3.7	3.75
31	9 30	4.2	12 0	4.2	4.2
Sept. 1	11 0	4.3	9 30	4.2	4.25
3	10 0	4.6	...	...	4.6
4	10 30	4.5	10 0	4.7	4.6
5	9 30	4.8	...	...	4.8
6	...	...	9 30	4.8	4.8
8	9 0	4.7	...	...	4.7
9	8 30	5.1	...	...	5.1
10	8 45	5.4	10 0	5.3	5.35
11	9 30	5.5	9 30	5.0	5.25
12	9 0	5.6	10 0	5.5	5.55
13	8 0	5.7	10 0	5.7	5.7
15	13 30	5.9	...	...	5.9
16	...	...	8 30	5.9	5.9
18	10 0	6.1	9 30	6.1	6.1
19	11 0	6.3	...	...	6.3
22	10 0	6.9	10 30	6.8	6.85
23	9 30	7.4	11 0	6.9	7.15
24	8 30	7.5	9 0	7.3	7.4
25	10 0	7.5	...	...	7.5
28	7 15	<7.4	...	...	<7.4
29	8 30	7.9	...	...	7.9
30	11 0	7.9	10 0	7.9	7.9
Oct. 1	9 0	<7.4	...	...	<7.4
2	9 0	8.0	8 30	8.1	8.05
6	10 0	8.5	...	...	8.5
9	9 0	8.8	11 0	8.9	8.85

The mean values given in the above table are plotted on the accompanying figure (fig. 1, Continuous Curve). As it was evident that we had caught the Nova on the 22nd increasing in brilliancy, it was thought of interest to insert on the curve the

magnitudes determined by other observers, not only for the sake of comparison but for determining more accurately the form of the light curve at this stage of the Nova's career.

For this purpose the two Harvard values (namely August 9, <9.5 magnitude; August 19, 4.8 magnitude) and the Swedish

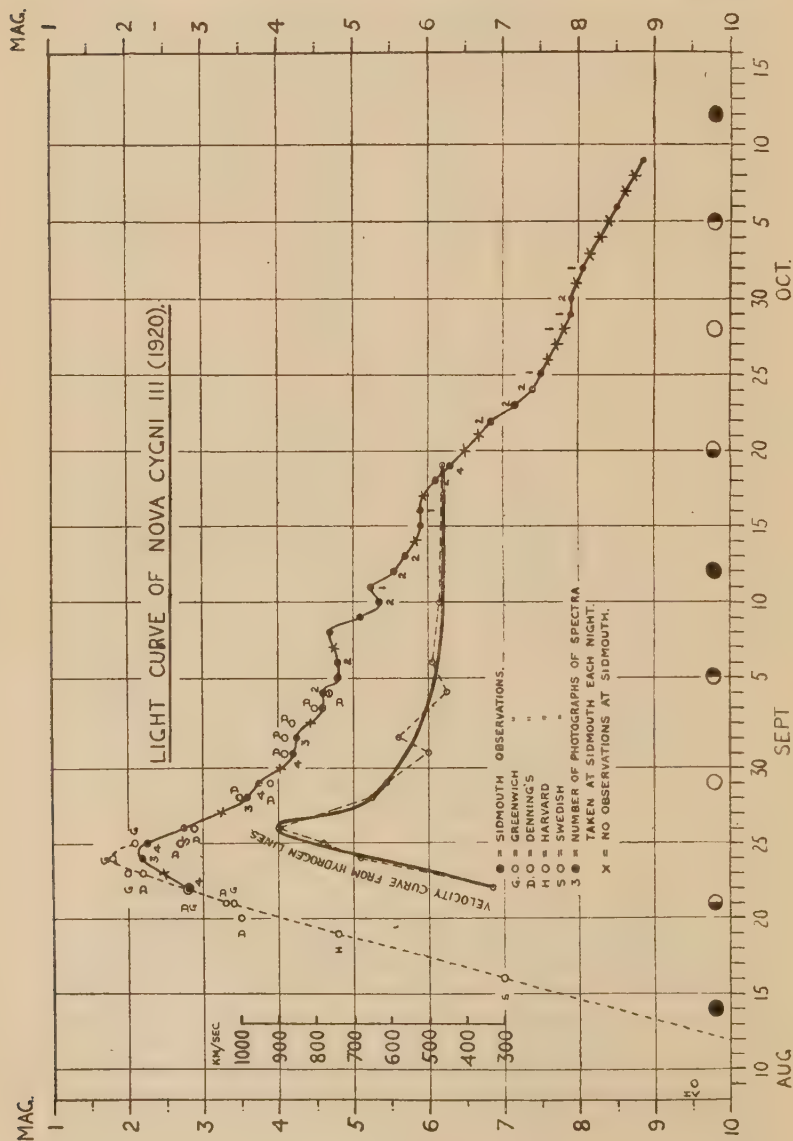


FIG. 1.

value (August 16, 7.0 magnitude)* have been inserted, followed by the published values given by Denning† and Greenwich.‡

These observations, indicated by the broken-line portion of the curve in the figure, show the rapid rise to maximum, a prominent feature of all Novæ. It will be noticed that after the maximum (August 24) was passed, the curve shows a fall of intensity (to August 28) nearly of the same rate as the rise. After that the rate of decrease is considerably diminished, and the curve displays a gradual decline, indicating small waves superimposed on it. These small waves suggest occasionally a three-day variation, the decline in magnitude being held up on August 29, September 1, and September 4. The next two subsidiary maxima are indicated on September 8 and 11, an interval of three days; but after that we have no observations on the nights of the 14th, 17th, or 20th to check its repetition.

It will be remembered that Nova Persei (1901) exhibited prominent three-day oscillations in magnitude just after it became a little fainter than 4th magnitude, these oscillations having an amplitude of a little more than a magnitude.§ This oscillation gradually extended into one of four days, the mean magnitude for numerous oscillations varying only slightly. It will be interesting to know whether other observers, who have probably made more accurate observations than we have, have detected a more regular oscillation in the light changes of the present Nova.

So far as the observations of magnitude have been made, it seems that the present Nova is decreasing its magnitude at a very much greater rate than many previous Novæ. If, for instance, we compare our observations with those of Nova Persei and Nova Aquilæ we find that this is the case.

Dr A. A. Rambaut|| has given the average rates of decrease in magnitude of the two Novæ mentioned above, and these we will take for comparison with the present Nova.

The following table shows the result:—

*Average Rates of Decrease of Magnitude of Nova Cygni,
Nova Aquilæ, and Nova Persei.*

Nova.	Date.	Days from Greatest Brilliancy.	Observed Mag.	Interval in Days.	Decrease of Mag. in Interval.	Rate of Decrease per Diem.
Aquilæ	1918 June 11	2	0.5	175	4.76	0.027
	1918 Dec. 3	177	5.26			
Persei	1901 Feb. 25	2	0.90	176	5.56	0.032
	1901 Aug. 20	178	6.46			
Cygni	1920 Aug. 24	0	1.8	39	6.2	0.159
	1920 Oct. 2	39	8.0			

* *Nature*, 106, 91.

† *Ibid.*, 105, 838; 106, 33, 59.

‡ *The Observatory*, September 1920, p. 330.

§ *Monthly Notices, R.A.S.*, 61, Appendix, p. 59.

|| *Ibid.*, 79, 112.

In the above we have employed the maximum value of the magnitude of Nova Cygni which was obtained at Greenwich, namely 1.8, and not our value, namely 2.2. The value for October 2 is our own determination. The above comparison clearly shows that the present Nova decreased in magnitude at a rate nearly five times as great as that of Nova Aquilæ or Nova Persei.

The Spectra in relation to the Light Curve.

As it is important to study the sequence of changes in the spectrum of the Nova in relation to the variations of magnitude, the number of photographs of the spectra taken each evening have been inserted on the light curve. It will be seen that these photographs are fairly evenly distributed over the curve and at the most crucial epochs—namely, August 22, when the Nova was brightening; on the 24th, when it attained its maximum luminosity; and on the 25th, when it had commenced to reduce its magnitude; four, three, and four photographs respectively were fortunately secured.

After October 2 cloudy nights and the faintness of the Nova prevented us from securing such a continuous record of the spectra. Up to that date, however, out of a total number of nights (Sundays included), namely forty-two, since and including August 22, satisfactory photographs were obtained on twenty-five of these nights, the largest interval of time between any two consecutive photographs being three days, and this only occurred twice. After October 2 photographs of the spectra were obtained on the following nights: October 22, 24, 25, 26, 27. As we had no magnitude determinations for these nights, a request was made to the Astronomer Royal for values he might have secured, to which he kindly replied. The only determination he had about those dates was taken from a photograph secured on the night of October 29, when the photographic magnitude was 9.1.

Outline of Sequence of Spectral Changes.

The first photograph of the spectrum was obtained on August 22, when the star was definitely on the up grade of its light curve (Plate 1, Nos. 2-3). In general terms the spectrum at this stage may be described as being almost identical with that of α Cygni. It possessed a continuous background with fine sharp absorption lines of hydrogen, silicon, and enhanced metallic origins, which corresponded to all the principal lines of α Cygni except for a considerable displacement of all lines towards the violet. This displacement was proportional to the wave-lengths of the lines and was attributed to radial motion. There were a few differences between the two spectra which appeared upon a more detailed comparison. The hydrogen lines, although very fine, were slightly broader than those in α Cygni, and the H and K lines of calcium

were very much broader and more diffuse. The remaining proto-metallic and other lines were almost identical, both in breadth and relative intensity, with the corresponding α Cygni lines. Although at this stage the spectrum was essentially one of absorption, there were also present a few faint bright lines, the chief of which were H_β , H_γ , H_δ and the enhanced iron lines at $\lambda 4924.1$ and $\lambda 5018.6$. These were almost undisplaced from their normal positions, being slightly on the red side of the corresponding absorption lines.

Several important changes appeared in its spectrum when the Nova was near the apex of its light curve. This occurred on August 24, and photographs taken on that date showed that the absorption lines were all broader and more diffuse than on August 22, and that there was a considerable increase in their displacement towards the violet (Plate I., No. 4). The bright lines had increased slightly in intensity and extended farther towards the violet end of the spectrum.

When the Nova was well down on the descending part of its light curve the stage of development of its spectrum was reached which is generally described as the "Typical Nova" stage. It was well shown on photographs taken on August 26 and onwards, and was marked by a considerable increase in intensity of the bright lines, which at this stage were fully as conspicuous as the absorption lines (Plate I., Nos. 5-6). These latter were a little narrower and less prominent than before, and the continuous background had faded slightly in intensity. The displacement of the absorption lines had reached a maximum on August 26, but it was noticed that the H and K lines of calcium were represented by comparatively fine absorption lines in a nearly undisplaced position as well as by the broad displaced bands. These fine lines were seen projected against the bright calcium bands, but were found to be approximately undisplaced. This stage was more persistent than the first, and lasted with only minor changes in detail from August 25. to September 10 approximately. The principal change which took place during this period was in the appearance of the bright hydrogen lines. On August 28 these appeared to have split up into doublets, or to have a strong dark reversal down the centre of each (Plate I., No. 7). Several of the other bright bands appeared also to exhibit this appearance of duplication, though in a slightly less marked manner. Photographs taken on Ilford panchromatic plates during this period showed a considerable number of lines in the green region which confirmed the general resemblance of the spectrum to that of α Cygni. The most prominent lines on the red side of H_β were the enhanced lines of iron at $\lambda\lambda 4924.1, 5018.6, 5169.2, 5234.8, 5276.2$, and 5316.8 , together with a trace of the silicon double at $\lambda 5042.0-5057.0$. These are all conspicuous lines in α Cygni, and were represented in the Nova both by bright and dark lines. H_α was too much out of focus to give any detailed information. It showed up strongly, however, on all these plates, and was evidently very bright for a considerable period of the Nova's history.

The next stage of development of the spectrum was marked by the appearance of the well-known broad band near $\lambda 4640$. This first showed signs of becoming prominent on September 6, and by September 12 it was very conspicuous indeed. By this time the continuous background of the spectrum had faded considerably and the absorption lines were much less conspicuous. The bright bands—especially those of hydrogen—had reached a very great intensity, and were the most prominent part of the whole spectrum (Plate 1, Nos. 8–10).

The first indication that the “nebular” stage had been reached was noticed on October 22, when the nebular line at $\lambda 5007$ was fairly well developed. There was, however, an interval of nearly three weeks between this date and the date of the previous negative, so that the actual time at which the nebular lines first began to appear in the spectrum is not quite certain. The photograph taken on October 22 showed that the continuous spectrum, together with the absorption lines, had practically disappeared. The bright lines of iron had also faded, and all that could be seen were the bright hydrogen radiations, the band at $\lambda 4640$, and the line N_1 at $\lambda 5007$. The N_2 line ($\lambda 4959$) was either absent or very faint, and no other nebular lines were noticed on this date. On October 24 both N_1 and N_2 were undoubtedly present, N_1 being much the stronger of the two. The absence of N_2 on the photograph of October 22 may probably be accounted for by under-exposure.

Persistency of the Bright α Cygni Lines.

It has been mentioned above that a great change took place in the spectrum of the Nova between August 22 and 24, the absorption lines being narrow and sharp on the former date and very much diffused and broadened on the latter. A glance at the spectra showed that practically all the prominent α Cygni lines had altered similarly. An attempt was therefore made to produce from a spectrum of α Cygni one like that of the Nova.

For this purpose a very recent spectrum of α Cygni was placed in an enlarging camera, and the spectrum was mounted in a frame which could be oscillated at right angles to the lines of the spectrum. In this way an α Cygni spectrum was produced which had all its lines bright and equally broadened, the amount of broadening having been adjusted by means of a cam to regulate the width of the lines.

The result was very interesting (see Plate I., Photograph 11). Isolated lines or pairs of lines, like those of hydrogen or the silicon and iron doubles, came out as broad isolated bands; but groups of close lines of different intensities, such as those between H_β and H_γ produced an integrated result through overlapping which corresponded in a remarkable degree to those of the Nova spectrum.

In this connection reference may be made to a preliminary

note on the new star in Perseus, in which Sir Norman Lockyer stated as follows:—*

“It may be assumed that, taking into consideration the broad nature of the Nova lines, if there is any genuine connection between them and α Cygni, any close groups of separately distinguishable lines in the latter spectrum would be thrown together in the Nova spectrum, and appear as broad bands. A good instance of this appears in Campbell's list. He records a band extending from $\lambda 4534$ to $\lambda 4501$. In the spectrum of α Cygni there is a strong line at each of the positions given, and between them there occurs a strong quartet of lines. The former are well-enhanced lines of titanium, and the latter of iron. It seems extremely likely, therefore, that the six lines thrown together produce the apparently continuous band observed by Campbell.”

In the present Nova there is no doubt that there is a strong band corresponding exactly in position with the quartet of enhanced iron lines $\lambda 4508\cdot5$ and $\lambda 4522\cdot7$.

No less interesting is the fact that the chief bands formed in this oscillated spectrum of α Cygni are reproduced in all the subsequent spectra of the Nova, even when it had reached the eighth magnitude (October 1) and was then in the λ “4640” stage of evolution.

To show this clearly, a reproduction of the oscillated spectrum of α Cygni is compared with the Nova spectrum of date September 10, its magnitude then being about 5.3 (see Plate I., Photographs 11 and 12). It will be seen in this that the four prominent bands between H_γ and H_δ correspond exactly with the broadened lines in α Cygni—namely, the silicon double $\lambda 4128\cdot6$, $\lambda 4131\cdot4$ (which is comparatively weak in the Nova); the enhanced iron double $\lambda 4173\cdot7$, $\lambda 4179\cdot0$; and the single enhanced iron lines $\lambda 4233\cdot3$ and $\lambda 4303\cdot4$.

Proceeding towards the red side of H_γ , the enhanced iron and Ti lines at $\lambda 4385\cdot9$ and $\lambda 4417\cdot4$ respectively are present, but weak; also the line at $\lambda 4481$ Mg. Then there follow three very prominent bands, and these correspond exactly with the enhanced iron line quartet at $\lambda 4508\cdot5$, $4515\cdot4$, $4520\cdot4$, and $4522\cdot7$ and the single enhanced lines at $\lambda 4549\cdot8$ and $4584\cdot0$. The next band in the Nova is a very broad one, being less bright in the centre. The first portion corresponds well with the enhanced iron pair at $\lambda 4629\cdot4$ and $4635\cdot3$, and the other portion is the strong unknown band at $\lambda 4640$.

Radial Velocities from the Hydrogen Lines.

It has already been remarked that the absorption lines in the earlier spectra of the Nova were considerably displaced towards the violet. This was regarded as a Doppler effect, and an attempt was made to obtain the radial velocities indicated. The prismatic camera which was employed in taking all the photographs was, of course, not a good instrument for this purpose, and the difficulty

* *Proc. Roy. Soc.*, 68, p. 122.

was increased by the fact that such a procedure had not been anticipated; so that the only data available for use were some photographs of α Cygni taken (for the purpose of general comparison) on separate plates, but with the same adjustments of the telescope as were used for the Nova. On the other hand, there were several photographs on each night from which to deduce a mean result, and, with such high velocities as were undoubtedly present, it was thought that a fairly good approximation might be obtained. Such an approximation would at least give a general idea of the way in which the velocity (as indicated by the hydrogen lines) varied from night to night during the early stages of the Nova's career. The attempt seems to have been justified by the agreement between different negatives taken on the same night, as shown in the table.

Radial Velocities of Nova Cygni.

Date.	Negative.		Radial Velocity.	Mean for each Day.	
	No.	G.M.T.		G.M.T.	Velocity.
		h m	km./sec.	h m	km./sec.
Aug. 22	1100	9 0	330	10 30	330
22	1102	10 0	335		
22	1104	12 0	335		
24	1105	15 30	690	15 45	680
24	1106	16 0	670		
25	1108	9 0	780	10 0	780
25	1109	10 0	775		
25	1111	11 15	780		
26	1112	9 15	930	10 15	900
26	1113	9 45	900		
26	1114	10 30	910		
26	1115	11 30	880		
28	1118	9 30	630	10 0	650
28	1119	10 30	670		
29	1121	9 0	645	10 45	610
29	1124	12 30	580		
31	1128	12 0	500	12 0	500
Sept. 1	1129	9 0	600	10 30	580
1	1130	10 30	550		
1	1131	11 30	590		
4	1132	10 30	410	10 0	450
4	1133	9 30	490		
6	1134	9 0	470	9 15	490
6	1135	9 30	510		
10	1136	9 0	470	9 0	470
19	1151	14 0	460	14 0	460

The method was similar to that of Orbinski, and consisted essentially in measuring the increase of distance between two lines in the Nova spectrum when compared with the corresponding distance in a Cygni. The lines used were H_{β} , H_{γ} , and H_{δ} . H_{ϵ} was too much merged into the H line of calcium, and the more refrangible members of the series were too faint in most of the photographs to allow of accurate measurement.

The results are all influenced by the radial velocity of a Cygni, and are also uncorrected for the velocity of the Earth.

These results were plotted on a diagram, and a smooth curve drawn through them, as shown in fig. 1. It will be noticed that this curve resembles to some extent the form of the light curve (shown in the same figure). There is an extremely rapid acceleration of velocity for a few days, until a maximum is reached on or about August 26. This is followed by an equally rapid decrease in velocity for a short time, after which, however, the rate of decrease quickly falls off and the velocity appears to tend towards a constant value of about 450 km./sec. It will be seen that the maximum velocity occurs about two days later than the maximum brightness, and is of a very decided character. During the period of increasing velocity the hydrogen lines were comparatively sharp and well defined, so that fairly accurate measurements could be made; but after the maximum had been passed the lines became very broad and diffuse. The results in this case are therefore not so reliable, and the irregularities in this part of the curve (as shown by the dotted line) are probably due very largely to accidental errors. It is interesting to note, however, that these irregularities correspond to some extent to similar irregularities in the light curve, which suggests that they may possibly be real, and due to a common cause underlying the variations of both light and velocity.

Breadth of the Bright Hydrogen Lines.

The bright lines of hydrogen varied considerably in breadth at different stages, and a series of measures were made of these with a view to discover the existence of any possible regularity in their variations. A curve which was plotted to represent these measurements showed a very rapid rise up to a fairly well-marked maximum on August 26. After this date the width of the lines decreased with great regularity at an almost constant rate except for a short and rather sudden increase between August 29 and September 1, and between September 16 and September 19. The effect due to differences of exposure was eliminated as far as possible by utilising all the photographs which had been secured on each night.

The "a Cygni Stage" in Novæ.

It seems probable that the stage which we may now designate as the "a Cygni stage" must always appear in the spectra of Novæ during that part of their history when they are rising to a

maximum brightness. Owing to the rapidity with which this rise is accomplished, it has usually happened that no spectroscopic observations have been made of Novæ until they have passed their maximum brilliancy; but we have now four cases of bright Novæ which afford definite evidence in favour of the above view, viz. Nova Persei (2), Nova Geminorum (2), Nova Aquilæ (3), and Nova Cygni (3). Each of these, when increasing in magnitude or at about maximum brilliancy, showed an absorption spectrum almost identical in character with that of α Cygni. Various observers describe this absorption spectrum rather differently. For example, Pickering* describes Nova Persei in general terms as similar to Rigel, but a more detailed discussion of the lines present shows that the spectrum more nearly resembles that of α Cygni than Rigel.† In the case of Nova Geminorum (2), Miss Cannon classifies the spectrum as F_5 and compares it with that of Procyon;‡ but, judging from the photograph which was published and the list of lines present, it was not very different from the α Cygni spectrum. Nova Aquilæ (3) was undoubtedly remarkably similar to α Cygni, according to Cortie§ and others, and we have already remarked that in the case of the present Nova the two spectra were almost identical. Novæ spectra during the stage of increasing brightness, and at about maximum brilliancy, may be described therefore as being very similar to α Cygni; and this may reasonably be regarded as a universal phenomenon, since in those cases where no direct evidence is available the later spectra show emission lines corresponding to all the important α Cygni lines, and are in all respects similar (except in certain details) to the later spectra of the four above-mentioned Novæ. For example, Pickering|| gives photographs of Nova Aurigæ (1892) and Nova Normæ (1893) which are almost identical, and which show those bright bands that in the present Nova we have attributed to the overlapping of certain enhanced iron lines which are characteristic of the α Cygni spectrum.

Spectroscopic Method for Discovering Novæ.

The conclusion has been drawn that *all* Novæ, a few days prior to and at their maximum brilliancy, exhibit an absorption spectrum typical of α Cygni. It is not known for how long a period this type of spectrum persists; but the fact that the bright enhanced metallic lines are prominent features for a long time during the star's waning suggests that possibly the absorption spectrum may be maintained for a considerable period when the star is increasing its magnitude.

* *Harv. Coll. Obs. Annals*, 56, No. III., 41.

† "On Some of the Phenomena of New Stars," *Solar Physics Committee*, 1914, p. 13.

‡ *Harv. Coll. Obs. Circulars*, No. 176.

§ *Monthly Notices, R.A.S.*, 79, 122.

|| *Astron. and Astrophysics*, 13, 40.

These ideas suggest a spectroscopic method for discovering and learning something of the early stages of a Nova's career.

The method consists in frequently photographing with an objective-prism telescope that part of the sky in and about the Milky Way, the region in which all Novæ appear. The instrument should be of large aperture and short focal length, and the prism should have a small angle. The field photographed should be as large as possible. The spectra of stars down to the sixth or lower magnitude should, if possible, be recorded.

Each plate should then be immediately examined for any spectrum of the α Cygni type, and if one be found, earlier photographs should be examined and further photographs should be taken on the following nights to observe whether any changes in the spectrum or magnitude were taking place.

The spectrum of α Cygni is a very simple one to pick out from the numerous spectra which would be recorded on the plate, and the fact that a very small percentage of stars exhibit this type of spectrum renders it comparatively easy to recognise at once.

The advantage of the above method is that should a Nova be discovered by this means, the previous photographs of the same region will contain a record of the spectroscopic changes which it has undergone. Thus one would be able to trace the sequence of changes at epochs in a Nova's career, of which at the present time we have no photographic records at all, and of which our ignorance is complete.

Conclusions.

The following are the main conclusions derived from the observations:—

§ 1. The light curve shows an abrupt rise to maximum on August 24, followed by a gradual decline, there being occasional secondary maxima during this decline. The rate of diminution in magnitude is about five times that of Nova Persei or Nova Aquilæ.

§ 2. The Nova when increasing its magnitude displayed a nearly complete absorption spectrum similar to that of α Cygni, with the exception of broad H and K lines and a few bright lines.

§ 3. At maximum magnitude the same spectrum was indicated, but all the lines were diffuse.

§ 4. At later dates the "typical Nova spectrum," the "4640" and the nebular stages were passed through in the order named. The bright enhanced metallic lines persisted well into the "4640" stage.

§ 5. The dark hydrogen lines indicated a variable motion in the line of sight towards the Earth, the velocities varying consecutively from 330 kms. per second on August 22 to a maximum of 900 kms. per second on August 26 (*i.e.* two days after maximum luminosity), and a gradual reduction to 460 kms. per second by September 19.

§ 6. The width of the bright components of the hydrogen lines varied nearly in the same manner as the velocity determined by the dark lines, both attaining a maximum value on August 26.

§ 7. On and after August 25 the bright hydrogen lines were split up into two parts by a reversal down the centre. Up to September 6 in the case of H_β the violet was stronger than the red component, after which date they became equal in intensity. In the case of H_γ , H_δ , and H_ϵ the red component was always the stronger.

§ 8. A discussion of the observations of previous Novæ seems to indicate that all Novæ, at and just previous to the maximum magnitude, and very probably before that, exhibit absorption spectra similar to α Cygni and maintain the bright enhanced metallic lines well into the "4640" stage.

§ 9. A spectroscopic method is suggested for discovering Novæ and obtaining early records in their life-history.

DESCRIPTION OF THE PLATE.

The spectra in this plate illustrate a series of progressive photographs of the Nova.

1. The spectrum of α Cygni, Aug. 26, 13^h 26^m G.M.T., taken with the same instruments and adjustments as the Nova spectrum. All wave-lengths given without notification of origin are "enhanced iron."

2. Nova, Aug. 22, 9^h 39^m G.M.T. Mag. 2.8 increasing. Shows dark lines sharp and similar to α Cygni. Few bright lines. Note breadth of H and K.

3. Nova, Aug. 22, 11^h 54^m G.M.T. Mag. 2.8 increasing. (From denser negative.)

4. Nova, Aug. 24, 15^h 16^m G.M.T. Mag. 1.8 maximum. Lines more diffuse. Velocity shift greater.

5. Nova, Aug. 25, 9^h 0^m G.M.T. Mag. 2.25 decreasing. Bright lines more conspicuous.

6. Nova, Aug. 26, 8^h 52^m G.M.T. Mag. 2.75 decreasing.

7. Nova, Aug. 28, 9^h 5^m G.M.T. Mag. 3.6 decreasing. Reversals in bright hydrogen lines. Bright lines more pronounced.

8. Nova, Sept. 10, 9^h 20^m G.M.T. Mag. 5.35 decreasing. $\lambda 4640$ developing. Continuous spectrum diminishing.

9. Nova, Sept. 18, 9^h 20^m G.M.T. Mag. 6.1 decreasing. $\lambda 4640$ well developed.

10. Nova, Sept. 23, 10^h 5^m G.M.T. Mag. 7.15 decreasing. Hydrogen lines narrowing.

11. α Cygni oscillated and reversed to show broad bands.

12. Same as No. 8 above, to compare with No. 11.

The Spectrum of Denning's Nova Cygni III. (1920).

(Communicated by the Director, Solar Physics Observatory, Cambridge.)

The news of Mr. Denning's discovery on August 20 of a new star in Cygnus arrived in Cambridge in the late afternoon of Saturday, August 21. The star was seen for a few minutes in the evening of the 21st through gaps between clouds, and its magnitude was estimated by reference to δ and θ Cygni as about 3.5 at 9.0 p.m., G.M.T.

On Sunday, August 22, 9^h 10^m–10^h 31^m, G.M.T., a photograph of the spectrum was obtained with the slit-spectrograph attached to the Huggins refractor. The slit, which had been recently

- 5018
 - 4924
 H
 - 4629
 - 4584
 - 4549
 - 4523 }
 = 4508 }
 - 4481 M_g
 - 4417 Ti
 - 4385
 H
 - 4303
 - 4233
 = 4173
 4179
 - 4131 }
 = 4129 }
 H
 - 4025 K₂
 - 4003
 H
 - 3933 Ca
 H
 H
 H
 H

1 2 3 4 5 6 7 8 9 10 11 12

reworked, was found later to have been far too narrow, and the spectrum was exceedingly faint; but it shows no sign of bright lines. Magnitude 2.8.

On Monday, August 23, 9^h 23^m–10^h 26^m, with carefully adjusted slit, another photograph of the spectrum was obtained in spite of considerable cloud and haze. It shows definite signs of an emission band near H_γ, and a broad absorption line of H_γ displaced to the violet. Measurements give a displacement of –5.3 tm., corresponding to a velocity of approach of –365 km./sec. Magnitude 2.0.

The next photograph was obtained on Thursday, August 26, 8^h 2^m–9^h 5^m, G.M.T. Measurements of the H_γ absorption line give a displacement of about –13 tm., corresponding to a velocity of about –890 km./sec. Metallic lines (chiefly enhanced iron, titanium, and probably chromium) by their displacements indicate a velocity of –870 km./sec. Magnitude 2.6.

Spectrograms were secured also on August 28, 29 and September 4, 6, 7, 10, 11, and 12. Magnitude gradually changed from 3.5 to 5.4.

Meanwhile a two-prism spectrograph was prepared for attachment to the Newall telescope. Parts of the original instrument had been taken to the Crimea in 1914, and are still at Odessa. A new camera was fitted and was ready for work by September 6, but cloudy nights interfered with observations until September 10. A good series of photographs was secured by Mr. Stratton and Mr. Manning on September 10, 11, 12, 16, 18, 19, and 26. By the last-named date the star had faded to about magnitude 7.

The spectrogram of September 11 shows a displacement of the absorption lines of the Nova corresponding to a velocity of about –735 km./sec. for several absorption lines of enhanced iron and titanium. The absorption lines of hydrogen, which had been up to this date broad and ill defined, now appear to be quadruple, with displaced components indicating velocities –810, –1200, –1370, –1780 km./sec. The bright emission bands are more clearly defined in contrast to the feebler continuous background; their width is now about 20 tm.

Measurements of metallic absorptions visible in the spectrogram for this date (September 11) give the following results:—

Measured Absorption Line.	Probable Source.	Displacement.	Velocity.
4457.9	Enh. Ti 4468.7	–10.8 tm.	–727 km./sec.
4460.6	He 4471.6	–11.0	–739
4497.5	Enh. Fe 4508.5	–11.0	–733
4504.6	„ 4515.5	–10.9	–726
4511.1	„ 4522.7	–11.6	–771
4523.1	Enh. Ti 4534.1	–11.1	–736
4553.3	„ 4564.0	–10.6	–699
4560.6	„ 4572.2	–11.6	–764
4572.8	Enh. Fe 4584.0	–11.2	–735

Mean – 37 km./sec.

Observations of the Magnitude of Nova Cygni, 1920 (Denning), made at the Radcliffe Observatory, Oxford. By Arthur A. Rambaut, M.A., D.Sc., F.R.S.

The first observations of the Nova were secured here on August 22, two days before it reached maximum brightness. On the 24th, owing to the prevalence of cloud and to the brightness of twilight, only rough observations were obtained. Since this date the star has been observed at every opportunity.

The proportional method of determining magnitude was adopted, the Nova being compared with two stars, one brighter and one fainter, and an estimate made of the ratio which the difference in brightness between each comparison star and the Nova bore to the difference in brightness of the two comparison stars.

At first the observations were made with the naked eye only. Slight optical aid became necessary between September 9 and September 27. From this date onwards the Barclay Equatoreal was used. The instruments employed are indicated in column 3 of Table II. as follows:—

- n.* Naked eye.
- f.* Dr. Rambaut's field-glasses (Ross's prismatic).
- b.* Dr. Rambaut's opera-glasses.
- b₁.* Mr. Balk's opera-glasses.
- B.* Barclay 10-inch Equatoreal. Power 45 used between October 26 and November 1, also on November 4 and 11; power 90 on October 25, November 4 and 5.
- F.* Finder ($2\frac{3}{4}$ -inch) of Barclay.
- P.* The 18-inch Guider of the Photographic Refractor and the Finder (3-inch) were employed on one occasion (see Notes, October 26).

A study of the light changes reveals at least three phases:—

- (1) After the attainment of the maximum brightness on August 24 a rapid decline at a rate of about 0.25 magnitude per diem until August 31 (7 days).
- (2) A slower but steady fall at the daily rate of 0.1 magnitude between August 31 and about October 18 (48 days).
- (3) Nearly stationary from October 19 onwards, with a tendency to *rise* at the end of the series.

The total decline in the first two months was about 7 magnitudes. This is greater than the fall of Nova Aquilæ or Nova Persei, which amounted to 5.6 and 5.2 magnitudes respectively in the corresponding interval.

No marked fluctuations of brightness, such as those observed in Nova Aquilæ and Nova Persei, are recorded; but on plotting the results some very slight oscillations are shown, with a *suspected* period of approximately 12 or 13 days, the maxima occurring on August 24 and about September 5, 18, 30, and October 11.

In Table I. below are given, a letter for reference, the names of the comparison stars used, their positions for 1920.0, and their magnitudes on which our estimates are based. The latter are taken from the *Revised Harvard Photometry and Supplement* for stars α to μ , and for the remainder from the B.D., reduced to the Harvard scale by means of a table given in the *H.A.*, 72, 217. The B.D. number is printed in italics when, owing to precession, the degree differs from that in column 4.

The last column of Table II. contains the magnitudes, deduced from the observations shown in column 4, for each observer. Corrections for atmospheric absorption have not been applied, being generally insensible, and in no case affecting the result by more than 0.02 magnitude.

TABLE I.

List of Stars used for Comparison with Nova Cygni.

Ref.	Name of Star.	R.A. 1920.0.	Decl. (N.) 1920.0.	Magni- tude.	Ref.	Name of Star.	R.A. 1920.0.	Decl. (N.) 1920.0.	Magni- tude.
		h m	° '				h m	° '	
a	γ Cygni	20 19	40 0	2.32	α	B.D. 2793	19 50	46 49	5.51
b	γ Draconis	17 55	51 30	2.42	β	2815	19 32	51 4	5.65
c	α Cephei	21 17	62 15	2.60	γ	2329	20 17	55 9	5.71
d	ϵ Cygni	20 43	33 40	2.64	δ	2623	20 4	52 55	5.72
e	δ Cygni	19 42	44 56	2.97	ϵ	2193	19 37	54 47	5.86
f	β Draconis	17 29	52 22	2.99	ζ	2324	20 4	56 6	6.18
g	β Cephei	21 28	70 13	3.32	η	2796	20 10	51 13	6.35
h	η Cephei	20 44	61 32	3.59	θ	2223	19 45	54 12	6.79
i	ξ Cygni	21 2	43 36	3.92	ι	2303	19 47	53 34	6.85
j	ι Cygni	19 28	51 34	3.94	κ	2657	20 12	52 53	7.02
k	31 Cygni	20 11	46 30	3.95	λ	2368	20 12	53 25	7.12
l	κ Cygni	19 15	53 13	3.98	μ	2613	20 1	52 21	7.63
m	ν Cygni	20 54	40 52	4.04	ν	2308	19 49	53 42	7.8
n	32 Cygni	20 13	47 28	4.16	ξ	2363	20 10	53 40	8.1
o	θ Cephei	20 28	62 43	4.28	$\omicron$	2328	19 55	53 34	8.1
p	33 Cygni	20 12	56 19	4.32	π	2339	19 59	53 17	8.2
q	B.D. +57° 2240	20 43	57 18	4.63	ρ	2326	19 54	54 10	8.3
r	θ Cygni	19 34	50 2	4.64	σ	2332	19 56	53 42	8.7
s	ψ Cygni	19 54	52 14	4.80	τ	2335	19 57	53 20	8.9
t	23 Cygni	19 52	57 19	5.04	υ	2330	19 55	53 14	9.1
u	B.D. +58° 2013	19 54	58 38	5.13	ϕ	2582	19 56	53 6	9.1
v	20 (d) Cygni	19 49	52 47	5.17	χ	2321	19 53	53 22	9.5
w	53 Draconis	19 10	56 43	5.24	ψ	2329	19 55	53 20	9.6
x	54 Draconis	19 12	57 34	5.26	ω	2589	19 57	53 3	10.0
y	26 (e) Cygni	19 59	49 53	5.28					
z	51 Draconis	19 3	53 16	5.35					

The position of the Nova for 1920.0 is R.A. 19^h 56^m, Decl. +53° 24'.

TABLE II.

Estimation of Magnitude.

G.M.T.		Ob- server.	Instru- ment Used.	Estimations.	Deducted Magni- tude.
1920.	h m				
Aug. 22	8 30	A.A.R.	<i>n</i>	e1N2c; e5N5d; e2N8a	2'83
	9 15	B.	,,	e1N2c; e1N3a; e2N3d	2'83
24	7 53	R.	<i>B</i>	See Notes.	(2'4±)
	8 45	B.	<i>n</i>	,,	(2'3±)
26	9 5	R.	,,	a7N3e; N=f($\frac{1}{2}$ wt.); d6N3e	2'85
	9 50	B.	,,	c1N9e; a5N5e; b4N6e; N=d	2'64
	10 10	A.A.R.	,,	a5N1e; d3N1e	2'88
28	9 0	R.	,,	k5N5e	3'46
	10 0	B.	,,	e1N3l; e2N5k; N=g	3'25
29	9 45	R.	,,	k3N7e; j2N8e	3'70
30	8 30	B.	,,	N=l, j, and k	3'96
	8 45	R.	,,	N=j, l, and k	3'96
	10 20	B.	,,	h3N2p; h3N2o; h3N1m; i1N1m; N=l, k, and j	3'98
31	9 20	R.	,,	p5N5k	4'13
	9 30	B.	,,	j1N1p; l2N3p	4'13
Sept. 1	8 30	R.	,,	p3N7j and l; n3N7k	4'16
	9 43	B.	,,	j3N1p; l2N1p	4'22
4	10 0	R.	,,	n4N7s; p3N7s; q1N7s; r3N7j	4'48
	10 0	B.	,,	N=p and o; j3N2q; j2N3t; j2N2s	4'35
6	8 15	R.	,,	s1N9p; N=r	4'70
	8 20	B.	,,	p5N5t	4'68
7	9 38	R.	,,	s1N9p; t1N2u; y5N5r	4'92
	9 45	B.	,,	r2N2t; q2N2t; r1N2v; r1N3y; N=s	4'82
9	8 30	B.	<i>f</i>	s3N1v; s3N2y	5'09
	9 30	B.	<i>n</i>	N=u; t2N2v	5'12
	10 0	R.	,,	s3N7v	4'91
10	8 40	B.	<i>b</i>	v1N4δ; v1N1z; s2N2δ; N=y	5'27
	10 30	R.	,,	v5N3δ; y2N8δ	5'44
	10 45	B.	<i>n</i>	N=w and x	5'25
11	10 0	B.	<i>b</i>	y1N6δ; v1N2a; s2N2e; v2N3γ	5'34
12	9 0	B.	<i>b</i> ₁	v3N2y; r3N2δ	5'27
	10 5	R.	<i>b</i>	v5N3δ	5'51
13	8 45	B.	,,	v2N1δ; y2N2β; s5N1γ; y4N1a	5'51
	9 35	R.	,,	δ3N7y; δ2N8v	5'60
14	9 10	B.	,,	y3N1δ; v3N1γ; N=β	5'61
15	8 50	B.	<i>b</i> ₁	β5N5δ; v9N1δ	5'68

TABLE II.—*continued.*

G.M.T.	Ob- server.	Instru- ment Used.	Estimations.	Deduced Magni- tude.
1920.	h m			
Sept. 16	8 50	B.	δ 2N3 η ; N= δ	5.72
	9 30	R.	N= δ	5.72 $\pm$
18	7 40	B.	N= ϵ ; δ 1N6 η	5.84
19	8 45	B.	δ 2N2 η ; γ 3N2 ζ	6.01
26	8 50	B.	θ 1 ι 1N	6.91
27	8 30	B.	" θ 1 ι 3N	7.03
	8 40	H.B.	ϕ 0m.1 < ι , $\frac{1}{2}$ m > ν ; λ 1N3 ξ	7.21
	9 0	R.	" κ 3N7 λ ; θ 7N3 ι	6.94
28	10 0	B.	" ι 2N4 ν ; λ 1N7 ξ	7.18
29	8 30	R.	" κ 6N4 λ ; θ 9N1 ι	6.96
	8 47	H.B.	" λ 1N2 ξ ; ι 3N5 ν	7.29
Oct. 2	7 45	B.	" ι 4N1 ν ; λ 2N2 ξ ; N= μ	7.57
9	7 30	B.	" π 2N3 τ ; σ 2N2 σ ; N= ρ	8.39
11	8 20	B.	" π 2N2 τ ; σ 4N2 σ	8.48
13	7 30	B.	" π 5N1 τ ; N= σ	8.74
18	8 30	B.	" τ 1N1 ν ; τ 1N5 ψ	9.01
25	7 30	B.	B ν 3N2 ψ ; τ 4N2 ψ	9.39
26	8 0	B.	P ν 3N3 ψ	9.35
	8 40	B.	B ν 3N3 ψ ; τ 4N6 ω	9.35
	8 40	B.	F ν 3N3 ψ	9.35
28	7 30	B.	B ν 3N3 ψ ; ϕ 3N2 ψ ; τ 4N6 ω	9.36
30	7 45	B.	" ν 3N7 ψ ; τ 5N5 ψ ; ϕ 5N5 χ	9.27
Nov. 1	7 45	B.	" ν 3N7 ψ ; τ 5N5 ψ	9.30
4	7 30	B.	" ν 1N9 ψ ; τ 4N6 ψ ; N= ϕ	9.14
5	7 30	B.	" ν 1N9 ψ ; N= ϕ ; τ 3N7 ψ	9.12
11	7 15	B.	" ν 1N9 ψ ; N= ϕ ; τ 4N6 ψ	9.14

Observers' Notes.

1920.
 Aug. 22. With the field-glasses the Nova is of slightly reddish tint as compared with α , γ , δ , and ϵ Cygni (A.A.R.).
 24. Nova compared with γ Cygni through a momentary break in the clouds, and estimated to be roughly of the same magnitude as that star. Slight haze: moonlight (B.). In the 10-inch Barclay equatoreal, power 90, the nucleus of the Nova was colourless, with a short red wing. The image of γ Draconis, which was approximately of the same order of brightness, contrasted strongly in colour with that of the Nova, γ Draconis being reddish-yellow. Clouds and mist rapidly coming up, prevented further observation (R.).
 26. Sky near zenith clear of cloud, but a little milky. Bright moonlight (A.A.R.). Sky very hazy: moonlight (B.).
 28. Difficult observations: sky hazy (R.). Rather difficult. Full moon (B.).

1920.

- Aug. 30. Examined Nova with the 10-inch Barclay, power 90, for character of image, and made the following comparisons with other stars. At the *normal focus*:—Nova, light yellow with red wing; γ Draconis, orange; κ Cygni, light orange; ι Cygni, white; 31 Cygni, deep orange; faint star near, blue. At the *extra-focus*:—Nova has a ruby centre to a light yellow disc; γ Draconis, red centre to yellow disc; κ and ι Cygni, colourless; 31 Cygni, deep orange. *Infra-focal images*:—Nova, yellow with red fringe; γ Draconis, similar to Nova; κ and ι Cygni, colourless; 31 Cygni, deep orange with red fringe (R.). Bright moonlight at 10^h 20^m G.M.T. (B.).
31. Rather difficult. Moonlight. Sky very hazy, with thin clouds passing at times (B.). Difficult; haze and cloud (R.).
- Sept. 1. In breaks (R.). Sky somewhat hazy (B.).
9. In breaks. Very difficult (R.). At 9^h 30^m G.M.T. observed through breaks in clouds (B.).
15. Comparisons made rather hurriedly through breaks (B.).
16. Very difficult in brief break (R.). Sky very clear (B.).
18. Through breaks in clouds (B.).
26. Bright moonlight (B.).
27. In the 10-inch, with power 90. Nova at *normal focus* stellar, colour pale yellow, or white, with deep red fringe. *Extra-focus*, image also stellar, ruby-coloured, with wide fringe tinged with blue. In the finder the colour of the image is reddish, rendering comparisons rather difficult (R.). Observations of comparatively little worth. Moonlight (H.B.). Sky fairly clear. Full moon. Nova rather difficult to see in white sky (B.).
28. Sky very hazy and bright moonlight (B.).
29. In the 10-inch the character of the image is similar to that described on the 27th (R.). Not a satisfactory observation (H.B.).
- Oct. 9. In the 10-inch, power 90, Nova distinctly reddish at stellar focus compared with B.D. + 53° 2335 (B.).
18. In the 10-inch, with power 90, Nova at *normal focus* has a pale orange nucleus with faint red fringe: at *extra-focal* setting, red nucleus with colourless fringe (B.).
25. Bright moonlight: sky clear (B.).
26. Sky slightly hazy. Bright moonlight. The image of Nova in the 18-inch guiding telescope of the photographic refractor is similar to that described on October 18 (in the Barclay 10-inch), except that at the *extra-focal* setting the nucleus is of a little deeper red colour, with a very pale electric-blue fringe (B.).
28. Sky rather hazy, with bright moonlight (B.).
- Nov. 4. Rather thick haze, otherwise sky clear. The same estimations of brightness were obtained with power 90 as with power 45 (B.).
5. Rather foggy (B.).
11. Sky clear but rather hazy (B.).

The observers were:—

Dr. A. A. Rambaut, indicated by A.A.R.	
Mr. W. H. Robinson,	„ R.
Mr. H. G. Scott Barrett,	„ H.B.
Mr. James G. Balk,	„ B

Radcliffe Observatory, Oxford:
1920 November 12.

The Spectrum of Nova Cygni III. By the
Rev. A. L. Cortie, S.J.

An unfortunate mistake, made by the Post Office officials, in the transmission of the telegram announcing the position of Nova Cygni, kindly sent by the Astronomer Royal, caused the observers at Stonyhurst to miss seeing the new star in a clear sky on August 22. Cloudy and hazy nights prevented further observations until August 29, when the star had fallen to magnitude 3.8. Some good photographs of the spectrum were then obtained with the Whitelaw 6-inch short focus prismatic camera on the nights of August 29, 30, and September 6, by Father J. Rowland.

The spectrum on those dates was a bright band spectrum, characteristic of the second stage in the progressive spectra of novæ. The bright hydrogen bands, which consisted of two components, extended on the average over 20 Å. units. Besides hydrogen, the most prominent radiations were due to enhanced iron lines, among which were 5316, 5169, 5019, and 4924. On September 6, when the star was 4.8 magnitude—a fall of a whole magnitude since August 29,—4924 alone of the four radiations named, left an impression on an isochromatic plate. Between H_{β} and H_{γ} were two prominent and very broad bands: the first extending from 4703 to 4628, and the second marked by three maxima corresponding to the iron lines 4584, 4550, and 4516. Between H_{γ} and H_{δ} the three most prominent radiations were identified as most probably 4303, iron; 4234, also iron,—a radiation strong in other novæ, Aurigæ, Persei, and Aquilæ,—and 4173, iron. The K band of calcium was also doubled and extended over 15 Å. units. On August 29 the spectrum extended far into the violet.

The brilliancy of H_{α} was very remarkable, and it maintained its predominance for a long period. On a plate taken on October 8, when the star had fallen below the eighth magnitude, this radiation was the only one that made an impression on the plate. The D_{β} line was photographed on August 30.

By allowing the star's image to trail very slowly, measurable plates were obtained with the Thorp 3-inch prismatic camera, on September 6, 11, and 19. The impression on September 11 is very strong, the star's image having been kept almost stationary. The longer focal length of this instrument, 50 inches, as compared with that of the Whitelaw camera, 30 inches, enables more precise measurements of the positions of the bright radiations to be effected. The magnitudes of the star on these three dates were 4.8, 5.4, and 6.3 respectively. A spectrum of α Cygni fits the centres of the bright hydrogen radiations, with its dark hydrogen lines, and consequently these points were selected as fiducial points in the measurements.

The widths of the hydrogen bands on these plates also are on the average about 20 Å. units, and show no change in width as the star waned in magnitude. They are doubles, the centres of the two bright components referred to the centres of the bands in-

dicating almost equal line-of-sight velocities of approach and recession. The measured values in kilometres per second, are, for September 6, at H_γ 366, at H_δ 345, and at H_ϵ 378, which gives a mean 363.

On September 6 the bright bands, besides the hydrogen radiations, were mostly due to spark or enhanced lines of iron, titanium, strontium, calcium, magnesium, vanadium, silicon, with three helium lines, and a complicated band extending from 4576 to 4688, which contained the 4640 radiations. This spectrum was similar to that measured for 1918 June 15, in the case of Nova Aquilæ.* The bands were, in general, sharper on their violet edges, and more diffuse on their red edges. They were in many cases about 12 to 18 Å. units in width.

The spectrum on September 11 showed more helium lines among those lines which were predominant. This spectrum, though weakened concomitantly with the fall of the star in magnitude, persisted at least until September 19. It was essentially the same spectrum as that of Nova Aquilæ on 1918 July 29,† except that there was no trace on the plates of the radiations N_1 and N_2 of gaseous nebulæ. The following table demonstrates the change in the character of the spectrum, from that of a spectrum of enhanced metallic lines to that merging into the type of helium stars. There is a possibility, however, that the stronger trail of the plate on September 11 might show the helium lines, which failed to make an impression on the weaker plate of September 6. But it does not seem to be likely.

Nova Cygni.

Helium Spectrum.

W.L.	I.	Sept. 6. W.L. I.	Sept. 11. W.L. I.	Sept. 19. W.L. I.	
3820	4		3821	5	
68	2				
89	10		3889	6	Coincides with H_ζ .
3965	4	3965	7	3967	7 67 3 „ „ H_ϵ .
4026	5		4028	3	
4121	3			4119	1
44	2				
4388	10	4389	3	89	4 86 2
4438				4437	4 39 2
72	6			4470	4 70 2
4686		4688	2	86	2 88 3
4713	3			4714	5
4922	4			4922	4

* *Monthly Notices, R.A.S.*, 79, 171 et seq.

† *Ibid.*, 79, 492.

The characteristic band 4640 was present in all the photographs of the spectrum taken between August 29 and September 19 discussed in this paper. The band as it appeared in Nova Aquilæ (1918) has been admirably unravelled into its probable components by Dr. Lunt.* The chemical origins of the component bands have also been assigned by Professor Fowler,† who finds that the radiations at 4634 and 4641 may be almost certainly identified with strong enhanced nitrogen lines; that at 4650 with two carbon lines 4651 and 4648, produced by strong electrical discharges; while the enhanced line of helium 4686 completes the tale.

In the following table are gathered together the measures of this band on the three dates specified. The wave-lengths are given with reference to fiducial points which, as already stated, are the centres of the broad H_γ and H_δ radiations. The three independent sets of measures give as the limits of the broad band, the mean wave-lengths 4575 and 4686. But the grouping of the composite bands differs on the three dates. On September 6 the band 4616-4662 was a composite band consisting of two members, which on September 11 were merged into a double band extending from 4618 to 4683. But this was probably due to photographic halation on the latter date when the image of the star was kept almost stationary, as this broad band is again split into two components on September 19.

The more refrangible member of the broad band, namely that extending from mean wave-length 4575 to 4602, covers the oxygen radiations 4591 and 4596, and is probably due to them. Similarly, on the less refrangible side of the broad band on September 11 and 19, is a subsidiary band, the mean wave-lengths of which on the two dates were measured as 4700 and 4707 respectively. This band also very probably represents the oxygen lines 4699 and 4706. Of these oxygen lines 4596 occurs in Wolf-Rayet stars; and, corresponding to 4699, a bright line was measured in Nova Aquilæ ‡ at 4697, which is described as broad, and which appears as 4698 in a Madrid plate of Nova Geminorum.§ Also the oxygen radiation 4706, to which corresponds 4707 of the plate of September 19, was recorded as 4705 in Nova Persei at South Kensington.||

The identification of these radiations with oxygen seems to be probable, seeing that other lines of oxygen, and notably the strongest line in this part of the spectrum, namely the double, with mean wave-length 4416, appears as a band 28 Å. units wide with mean wave-length 4414.

* *Monthly Notices, R.A.S.*, 80, 530.

† *Ibid.*, 80, 695.

‡ *Ibid.*, 79, 495.

§ *Phenomena of New Stars*, South Kensington, 45.

|| *Ibid.*

*Nova Cygni.**The Band $\lambda 4640$.*

Sept. 6.	I.	Sept. 11.	I.	Sept. 19.	I.	Probable Origins.
$\lambda 4576$	81 } 2	$\lambda 4571$	86 7	$\lambda 4579$	91 5	O 91
85						
91						
4603	97 } 3	4601		4603		O 96
16	29 } 3	18	51 } 51 8	25	47 8	N 34
42						N 41
42						C 48
62	52 } 2			70		C 51
66	77 } 2	83		74	81 3	He 89
88						
		86	00 5	96	07 3	O 99
		4714		4718		O 06

In the composite band 4640, not only are radiations present due to enhanced nitrogen and helium, but also radiations due to carbon under especially heavy electrical discharges. This band becomes more pronounced as new stars wane in luminosity. When it is very bright, the enhanced lines of metallic spectra due to spark discharges have disappeared.

Again, the order of the various phases of the spectrum, F, A, B, P, O, occur successively as the star becomes dimmer. But this order is that of giant diffuse stars, and is generally ascribed to temperature. Certainly a B-type star is regarded as having a higher surface temperature than an A-type star. And yet in a new star the change from the A type to the B type is generally accompanied by a fall of about 4 magnitudes, or 40-fold in luminosity.

But if, following a suggestion made to me by Dr Hemsalech, we regard the changes in the various types of spectra as due not primarily to temperature, but to changes in the value of the electrical field, these anomalies may be explained. The clue is furnished by the very strong electrical fields needed to excite the carbon constituents of the 4640 band. In the very early stages of high temperature in the constituent gases of new stars, the ionisation would be extremely active. Hence a strong electrical field could not be established. But with a falling temperature, indicated by the star's fall in magnitude, the electric field would become correspondingly greater. Hence the brightening of the band 4640.

Another great difficulty in the interpretation of the spectra of

new stars lies in the practically permanent widening of the bright hydrogen bands for several months, with the associated high line-of-sight velocities. But these hydrogen bands show much structure. In the star now discussed they were double bands. In Nova Aquilæ the structure was triple.

Strong electrical fields might possibly account for these bands.

Our last observation of the spectrum of the nova was made visually on October 18, with a McClean star spectroscope attached to the 15-inch equatorial. We could not see H_{α} , but only a green ray, which was probably $\lambda 5007$.

Summary.

1. The spectral changes in Nova Cygni have been normal, the enhanced metallic line spectrum merging into the helium star type spectrum between September 6 and 11.

2. The average breadth of the hydrogen bands was about 20 Å. units. The bands were doubles, and the line-of-sight velocity of the components was of the order of 360 km. per second.

3. In the composite band $\lambda 4640$, besides carbon, nitrogen, and helium, oxygen is also probably present.

4. It is suggested that the order of the spectral changes F, A, B, P, O, corresponding to the fall in magnitude in new stars, can be explained by the formation of strong electric fields resulting from the fall in temperature.

Stonyhurst College Observatory :
1920 November 6.

Visual and Photographic Observations of Nova Cygni 3, made at the Royal Observatory, Greenwich. By W. J. Luyten. (Plate 2.)

(Communicated by the Astronomer Royal.)

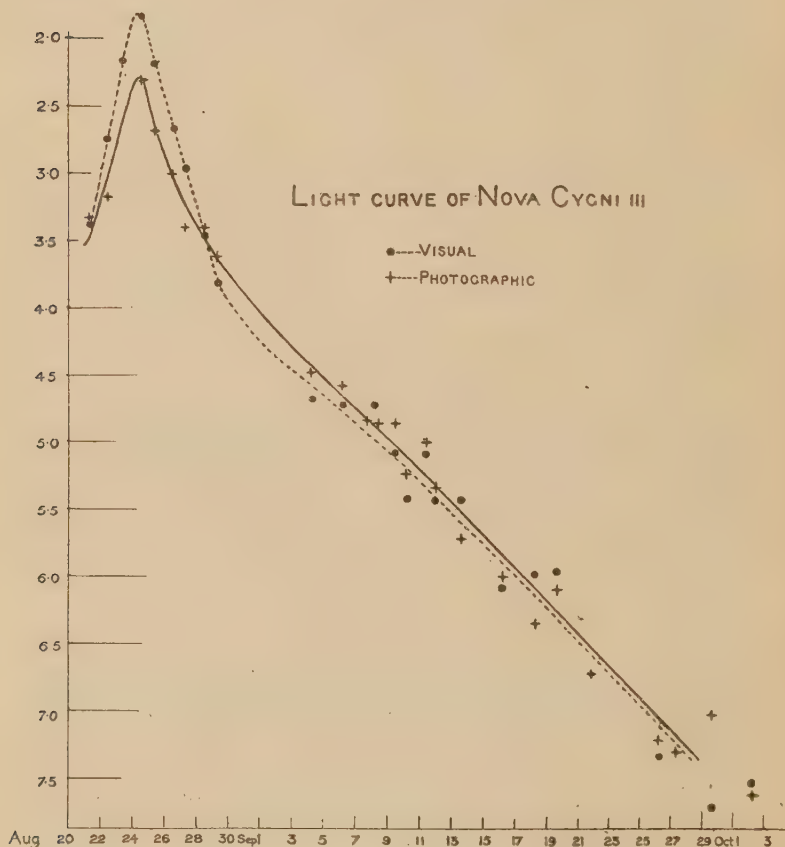
A telegram from Mr. Denning, announcing the discovery of Nova Cygni 3, was received at Greenwich on August 21, and since that date visual estimates were made and photographs taken of the Nova on every suitable night.

In the beginning, when the Nova was bright, all the visual estimates were made by the naked eye; later on, by means of a field-glass or a small telescope. The magnitudes of the comparison stars employed were all taken from the *Harvard Annals*.

The results, corrected for atmospheric absorption, are given in Table I., cols. 1-5, which needs no further explanation.

The photographic observations were all made with the 26-inch refractor of the Royal Observatory. As direct comparisons of the

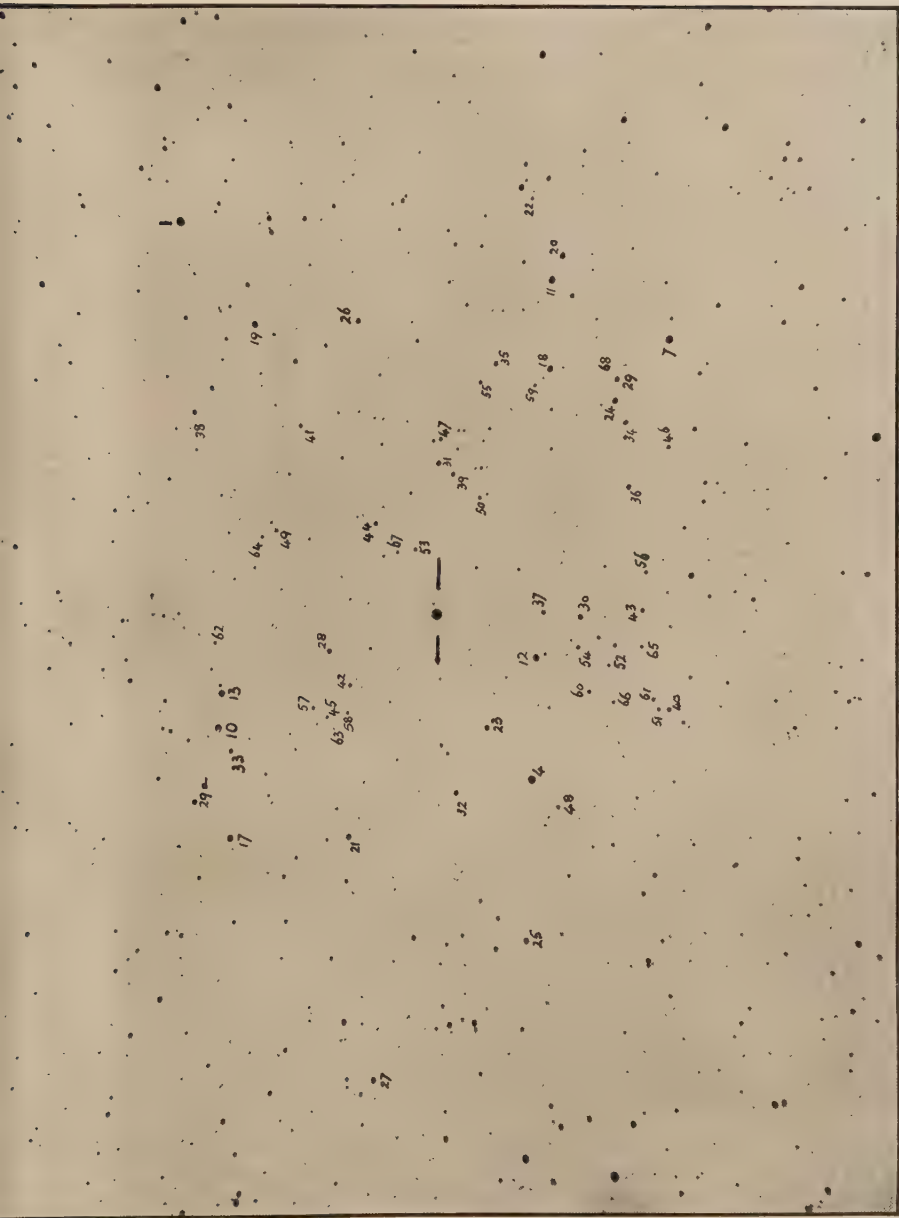
Nova with bright Polar Standards could only be made on good nights, which were not very frequent, the comparison had to be made with the stars immediately surrounding the Nova. At the scale of the 26-inch ($1\text{ mm.} = 30''$) the measurable field is only about $40'$ in diameter, and the brightest stars within these limits are $9^{\text{m.0}}$. In order to make the image of the Nova comparable



with stars of this brightness, its light was cut down by nearly five magnitudes by means of a rotating shutter with sectorial opening, as is used in parallax work at Greenwich.

As, however, this brought the Nova down only to seventh magnitude, when it was at its maximum, a diffraction grating was placed in front of the objective, which gives diffracted images $2^{\text{m.66}}$ fainter than the central image. This method of determining the magnitude of the Nova involved the knowledge of the exact amount of light cut down by the occulting

Nova Cygni III. 1920.



From Photograph taken at Royal Observatory, Greenwich, with 30-inch Reflector, 1920 October 2.
Exposure 30 minutes.

shutter and of the exact magnitudes of the stars surrounding the Nova.

The occulting shutter interval was determined by comparing the occulted image of stars from 4^m-7^m with Polar Standards between 9^m and 12^m .

A check hereupon was secured by comparing the occulted image of Polaris ($2^m.7 + 4^m.7 = 7^m.4$) with the diffracted image of δ Urs. Min. ($4^m.5 + 2^m.7 = 7^m.2$). These determinations yielded a value of $4^m.68 \pm 0^m.11$ (m.e.).

Although this result rests on only four plates, it is not likely to be much in error, as photographic magnitudes, determined by the shutter method, compared with those obtained by direct comparison on the Pole on first-class nights, showed only small and non-systematic differences.

On good nights plates were taken with exposures of equal lengths on the Pole and the field, to determine the magnitudes of the field stars. Each star was measured on at least three plates; the plates were measured in a duplex micrometer in which the star images were compared with a set of images of different exposures of one star, taken with the same instrument. To determine the brighter field stars, a diffraction grating was used, which at the same time served as a check on the correctness of the scale. The magnitudes of Polar Standards used for this purpose are those given by Chapman and Melotte in *M.N.*, 74, 1. A correction for atmospheric absorption was applied according to the values given by Schwarzschild in *Göttingen Aktinometrie*.

In Table II. are given the co-ordinates and magnitudes of 68 stars surrounding the Nova. In the adjoining plate, which is enlarged from a photograph taken with the 30-inch reflector, are inserted the numbers of all these stars, which will facilitate identifying them.

The photographic magnitudes of Nova Cygni 3 determined by the above-described method are given in Table I., cols. 6-8; these values are plotted, and a provisional light-curve is drawn in the adjoining diagram: dots and dotted line indicating the visual, crosses and full line indicating photographic magnitudes and light curve. The deviations from a smooth curve are not large enough to admit fluctuations; but, of course, this cannot be decided before observations of many observers are compiled.

TABLE I.

Magnitudes of Nova Cygni 3.

Date.	G.M.T.	Vis. Mag.	Instr.	Remarks.	Date.	G.M.T.	Photo. Mag.
	h m	m				h m	m
Aug. 21	10 0	3'37	n	■	Aug. 21	10 50	3'34
22	8 10	2'75	n	I	22	10 46	3'19
22	13 10	2'80	f	I	24	8 54	2'32
23	10 30	2'16	n	3	25	8 18	2'68
24	8 15	1'82	n	I	26	9 30	3'01
25	10 20	2'19	n	3	27	10 6	3'40
26	8 10	2'69	n	I	28	9 0	3'41
26	14 0	2'81	n	I	29	9 23	3'63
27	10 0	2'97	n	I	Sept. 4	9 21	4'49
28	8 45	3'46	f	I	6	8 23	4'58
29	8 10	3'81	f	2	8	10 18	4'82
Sept. 4	9 30	4'68	f	I	9	7 53	4'85
4	10 20	4'68	f	2	10	8 27	5'25
6	8 10	4'72	f	I	11	10 50	5'02
8	10 0	4'72	f	3	12	8 55	5'36
9	8 0	5'08	f	3	13	9 19	5'84
10	8 10	5'44	f	2	16	13 33	6'01
11	11 0	5'08	f	I	18	8 47	6'34
12	10 0	5'44	f	I	19	7 36	6'09
12	12 30	5'54	f	I	21	10 7	6'65
13	9 20	5'44	f	3	26	7 13	7'20
16	13 45	6'09	f	I	27	8 7	7'30
18	9 5	5'99	f	I	29	7 28	7'03
19	8 10	5'92	f	I	Oct. 2	8 26	7'62
26	9 0	7'34	f	3			
27	7 10	7'30	t	I			
29	6 40	7'71	t	2			
Oct. 2	7 15	7'54	t	I			

1. Fine.

2. Through clouds.

3. Difficult observation.

n. Naked eye.

f. Field-glass.

t. Small telescope.

TABLE II.

No.	Co-ordinates.		Mag.	No.	Co-ordinates.		Mag.
	α .	y .			α .	y .	
			m				m
1	-16'0	+ 9'8	8'95	35	-10'3	+ 3'0	12'33
2	+23'3	- 6'8	8'97	36	- 5'0	- 8'4	12'33
3	- 2'8	+17'9	9'04	37	+ 0'0	- 4'8	12'33
4	+ 6'9	- 4'1	9'19	38	- 8'6	+ 9'4	12'59
5	- 6'9	-18'6	9'20	39	- 5'8	- 1'2	12'63
6	-29'0	+ 4'1	9'67	40	+ 4'1	- 9'8	12'63
7	-11'1	-10'2	9'70	41	- 7'9	+ 5'1	12'73
8	-28'9	- 3'3	9'93	42	+ 2'8	+ 3'2	12'74
9	- 2'9	+17'8	9'97	43	+ 0'0	- 8'9	12'75
10	+ 4'5	+ 8'7	10'06	44	- 3'8	+ 2'1	12'77
11	-13'7	- 5'4	10'28	45	+ 3'8	+ 4'8	12'87
12	+ 1'9	- 4'4	10'28	46	- 6'9	-10'1	13'08
13	+ 3'0	+ 8'5	10'45	47	- 7'2	- 0'7	13'20
14	+ 1'8	-21'8	10'52	48	+ 8'1	- 5'2	13'22
15	+ 3'6	+17'9	10'57	49	- 3'6	+ 6'2	13'23
16	+19'1	+ 2'6	10'57	50	- 4'8	- 2'2	13'24
17	+ 9'0	+ 8'3	10'71	51	+ 4'2	- 9'4	13'25
18	-10'0	- 5'3	10'94	52	+ 1'5	- 7'7	13'27
19	-12'1	+ 6'8	11'01	53	- 2'7	+ 0'5	13'29
20	-14'7	- 5'9	11'19	54	+ 1'5	- 6'2	13'30
21	+ 9'1	+ 3'4	11'22	55	- 9'6	- 2'4	13'32
22	-17'6	- 4'2	11'25	56	- 1'5	- 9'0	13'35
23	+ 4'7	- 2'3	11'37	57	+ 3'2	+ 5'4	13'36
24	- 8'6	- 7'9	11'53	58	+ 4'0	+ 3'4	13'40
25	+13'6	- 3'8	11'53	59	- 9'4	- 4'6	13'48
26	-12'2	+ 2'6	11'71	60	+ 3'4	- 6'6	13'49
27	+22'5	- 3'6	11'72	61	+ 3'8	- 9'2	13'50
28	+ 1'4	+ 4'1	11'75	62	+ 1'0	+ 8'8	13'50
29	- 9'5	- 8'0	11'86	63	+ 4'1	+ 4'2	13'50
30	+ 0'2	- 6'3	11'91	64	- 3'4	+ 6'8	13'54
31	- 6'2	- 0'6	12'08	65	+ 1'6	- 8'8	13'54
32	+ 7'4	- 1'0	12'12	66	+ 3'8	- 7'6	13'55
33	+ 5'4	+ 8'2	12'21	67	- 2'6	+ 1'2	13'70
34	- 7'7	- 8'4	12'32	68	-10'0	- 7'3	13'73

I am greatly indebted to Sir Frank Dyson, Astronomer Royal, for permitting me to use the Thompson Equatorial for this purpose, and for the interest he took in this work. I also wish to express here my best thanks to Mr. Melotte and Mr. Davidson for their valuable help during the whole undertaking.

University Observatory,
Leiden, Holland;

1920 October 25.

On the Presence of Absorption Lines of Nitrogen and Oxygen in the Spectra of Nova Aquilæ III. By F. E. Baxandall, A.R.C.Sc.
(Plate 3.)

(Communicated by the Director, Solar Physics Observatory, Cambridge.)

In a recent paper* on "The Spectra of Nova Aquilæ No. 3," Dr. Lunt discusses the pair of strong dark lines at $\lambda\lambda$ 4054, 4060 (1918 July 15), the variations of which pair from day to day had previously been investigated by Paddeock† and other observers.

In a short note‡ "On the Identity of a Pair of Strong Lines of Peculiar Behaviour in the Spectra of Nova Aquilæ III," I indicated that I had come to the conclusion that this pair of nova lines could be identified with a pair of abnormal nitrogen lines at $\lambda\lambda$ 4097·4, 4103·5 which had been found in the Kensington spectra some years ago, and at that time identified with lines in the spectra of ϵ Orionis and kindred stars. As the detailed results of a reduction and discussion of an excellent series of Nova Aquilæ spectra (kindly sent by Dr. Plaskett) on which I have been for some time occupied were intended for later publication, I gave in the note mentioned merely the general statement that "whenever the presence of other nitrogen lines in the spectra made comparison possible, the nova lines in question were found to be ascribable to the two abnormal nitrogen lines 4097·4, 4103·5, partaking of the same velocity displacement as many other well-authenticated lines of nitrogen and oxygen in the spectrum of Nova Aquilæ."

I propose to anticipate the publication of the complete results of my work on the spectrum of Nova Aquilæ III. and give the results which directly bear on a question raised by Dr. Lunt§ as to the validity of the identity which has been suggested for certain nova lines with lines of nitrogen and oxygen. I would first like to make a few general remarks relating to the presence of nitrogen and oxygen lines in novæ spectra. From his researches on the spectra of Nova Geminorum No. 2, Mr. F. J. M. Stratton concluded that at certain stages of the spectra the absorption lines of nitrogen and oxygen are present, and he published|| an account of this in a "Note on the Absorption Spectra of Nova Geminorum." So far as I know, none of the numerous papers published—either before or after Stratton's note on Nova Geminorum—on the spectrum of Nova Aquilæ makes any reference to the occurrence of absorption lines of either nitrogen or oxygen.¶ Lunt definitely expresses his

* *M.N., R.A.S.*, 80, 699. † *Pub. Ast. Soc. Pacific*, 31, 56.

‡ *Ibid.*, 31, 297.

§ *M.N., R.A.S.*, 80, 700. || *Ibid.*, 79, 366.

¶ In a note on "The Spectrum of Nova Lyrae, 1919" (*Pub. Ast. Soc. Pacific*, 32, 154), Adams and Joy record absorption lines at measured

$\lambda\lambda$ 4573, 4579, 4585, 4592, 4602, 4615, 4622,

and say that "they are probably due to oxygen and nitrogen." There can be little doubt that the first six of these correspond to the nitrogen lines

4602, 4607, 4614, 4622, 4631, 4643,

and the last to the double oxygen line 4649, 4651, showing in that part of the spectrum a displacement of about -29 tenth-metres.?

doubts as to their existence in the Nova Aquilæ spectra. Thus, in his second paper on the spectra of Nova Aquilæ,* he says, of the spectrum of June 15: "Between the iron lines 4495 and 4679 the spectrum is . . . crossed by a number of rather broad, ill-defined maxima and minima which could not be interpreted. The measures indicate that the air-group 4591-4706 is absent. The air lines were plotted with displacements -1661 km./s. and -2285 km./s., but neither coincided with the diffuse lines in the nova spectrum." But the nitrogen and oxygen lines have a larger displacement (-2749 km./s. from the mean of six selected lines on June 15), and if the corresponding correction be applied for this displacement, henceforward in this paper referred to as displacement 3, the interpretation of most of the diffuse lines as due to either nitrogen or oxygen becomes very probable.

In his most recent paper Lunt says: † "On these plates (July 2, 15) there are no indications of the characteristic strong triplet 4070-2-6 or other strong lines of oxygen with the same displacements as the dark pair, and, indeed, on no other of the Cape plates have oxygen lines been seen with this or any other displacement." From this it appears that Dr. Lunt doubts the existence of absorption lines of oxygen in *any* of his spectra.

Many of the ordinary lines of nitrogen and oxygen first reveal themselves in the spectrum of June 13, intermixed with the α Cygni lines (of different displacement) which were so prominent on the earlier dates, June 10, 11, but which by June 13 have weakened considerably. These air lines persist in greater or less profusion through the spectra of June 14, 15, 17, 18, 19, 20, 21, but by June 22 they have disappeared, except for traces of a few of the stronger lines, and beyond June 22 they are apparently lacking altogether.

With regard to the identity of the strong nova pair in question with the abnormal nitrogen lines 4097, 4103, the spectrum of June 15 supplies the best evidence, as, although the abnormal lines are then rather vague, the ordinary nitrogen and oxygen lines which furnish the clue as to displacement are, in the same spectrum, at their best so far as intensity is concerned. This is the date for which Lunt states he has not been able to trace the oxygen lines.

The detailed results from my measures on Plaskett's plate of June 15 are given in Table I. The gaseous lines in question are not of the same order of sharpness as the α Cygni lines and hydrogen lines of the earlier spectra, and the same accuracy of setting as on the sharp lines can hardly be expected. Consequently, the residuals are rather larger than those in the reductions of the earlier spectra, but the multiplicity of the agreements and grouping of the lines, combined with the direct comparison of the nova spectra with those of nitrogen and oxygen, enlarged approximately to the same scale, leave no doubt as to the reality of

* *M.N., R.A.S.*, 80, 521.

† *Ibid.*, 80, 701.

the identity. In Table I. the corrected wave-lengths are obtained from the measured wave-lengths by applying the correction for a mean velocity of -2749 km./s.

TABLE I.

Nitrogen and Oxygen Lines in Spectrum of Nova Aquilæ III., June 15.

(The selected lines used for estimation of velocity shift are :

4317'25 O, 4319'79 O, $\left. \begin{matrix} 4415'07 \\ 4417'04 \end{matrix} \right\}$ O, 4607'34 N, 4630'73 N, 4661'76 O.)

(Mean velocity -2749 km./s.)

Measured λ .	Observed λ (corrected for Displace- ment 3).	λ of Laboratory Equivalent.	Observed minus Tabular λ .	Origin.	Remarks.
3936'66	3973'08	3973'44	- '36	O	Weak. Sharp.
3958'45	3995'07	3995'26	- '19	N	Centre of most intense part of narrow band.
4031'99	4069'29	4070'04	- '75	O	Fairly strong, hazy.
4034'90	4072'23	4072'40	- '17	O	„ „ „
4038'06	4075'41	4076'08	- '67	O	Weak.
4060'78	4098'34	4097'43	+ '91	N	Broad and hazy. Fairly strong. Difficult.
4065'73	4103'34	4103'46	- '12	N	„ „ „ „ „
4277'03	4316'61	4317'27	- '66	O	Fairly strong, sharp. Possible blend with p Ti 4300'21 (Disp. 1).
4280'03	4319'64	4319'78	- '14	O	Fairly strong, sharp. Possible blend with p Fe 4303'3 (Disp. 1).
4297'21	4336'98	4337'01	- '03	O	Weak, hazy. ?double. Possible blend with p Ti 4321'2 (Disp. 1).
4307'68	4347'54	$\left\{ \begin{matrix} 4347'54 \\ 4348'14 \end{matrix} \right.$	- '30	$\left. \begin{matrix} O \\ N \end{matrix} \right\}$	Sharp, strong. Chiefly due to H γ (Disp. 2).
4310'24	4350'12	$\left\{ \begin{matrix} 4349'52 \\ 4351'35 \end{matrix} \right.$	- '32	$\left. \begin{matrix} O \\ O \end{matrix} \right\}$	Rather weak, hazy.
4326'34	4366'37	4367'03	- '66	O	Middle of broad absorption.
4375'64	4416'09	$\left\{ \begin{matrix} 4415'07 \\ 4417'14 \end{matrix} \right.$	- '01	$\left. \begin{matrix} O \\ O \end{matrix} \right\}$	Strong, hazy. Possibly blended with p T 4399'94 (Disp. 1).
4547'61	4589'69	4591'13	- 1'44	O	Fairly strong. ?double. Blend with p T 4572'16 (Disp. 1).
4553'74	4595'87	4596'31	- '44	O	Weak.
4558'32	4600'50	4601'67	- 1'17	N	Strong, fairly sharp. Blend with p F 4584'02 (Disp. 1).
4564'55	4606'78	4607'34	- '56	N	Fairly strong ?double. Blend with p T 4590'13 (Disp. 1).
4572'24	4614'55	4614'05	+ '50	N	Hazy. ?double.
4580'67	4623'06	4621'57	+ 1'49	N	Rather indefinite.
4588'92	4631'38	4630'73	+ '65	N	Strong, hazy.

TABLE I.—*continued.*

Observed λ.	Observed λ (corrected for Displace- ment 3).	λ of Laboratory Equivalent.	Observed minus Tabular λ.	Origin.	Remarks.
99'26	4641'81	$\left\{ \begin{array}{l} 4641'94 \\ 4643'27 \end{array} \right.$	- '79	$\left. \begin{array}{l} O \\ N \end{array} \right\}$	Very hazy. Difficult.
58'21	4650'84	$\left\{ \begin{array}{l} 4649'25 \\ 4651'00 \end{array} \right.$	+ '72	$\left. \begin{array}{l} O \\ O \end{array} \right\}$	Fairly strong. Blend with p Cr 4634'25 (Disp. 1).
19'72	4662'45	4661'76	+ '69	O	Hazy, probably double.
33'93	4676'81	4676'34	+ '47	O	Fairly strong, hazy.
80'36	4925'53	4924'95	+ '58	O	Narrow, superposed on bright H β .
96'45	4941'76	4941'22	+ '54	O	Probably due almost solely to p Fe 4924'1 (Disp. 1).

Mean Velocity in km./s. (from all the above lines) = - 2757.

(from six selected lines) = - 2749.

Mean Diff. (Observed - Tabular λ, neglecting sign) = 0'57 tenth-metre.

(" " " " including sign) = - '08 tenth-metre.

A glance down column 4 of Table I. will show where the few cases of high residuals occur. Apart from the difficulty of getting accurate settings on the majority of lines in the spectrum, owing to their hazy and indefinite nature, it must be remembered that the spectrum on this date consists of lines of at least three different displacements, and some of the high residuals are probably due to the measured lines being blends of different lines not belonging to the same displacement. Thus, measured line 4558'32 is almost certainly a blend of p Fe 4584'0 of displacement 1 with N 4601'67 of displacement 3. Again, measured line 4547'61 is probably a double with the more refrangible component identifiable with p Ti 4572'13 of displacement 1 and the other component with O 4591'13 of displacement 3. This nova line is rather broad, and, measured as one line, gives a residual of + '95 tenth-metre when considered as identical with p Ti 4572'13 (Disp. 1) and - 1'44 tenth-metres when ascribed in its total aspect to the oxygen line 4591'13 (Disp. 3). Special reference may be made to line 4375'64. So far as position only is concerned, this might be attributable to p Ti 4399'94 (Disp. 1) or the double oxygen line 4415'07, 4417'14 (Disp. 3). It is, however, much too broad to be due solely to the former, and, in the light of the general feebleness in this spectrum of the enhanced titanium lines, it is fairly safe to assume that it is produced chiefly by the oxygen lines. Similarly the two lines at measured $\lambda\lambda$ 4277'03, 4280'03 are too prominent to be due solely to p Ti 4300'21 and p Fe 4303'3 of displacement 1, a far more likely origin being the double oxygen line 4317'27, 4319'78 of displacement 3. Moreover, these two nova lines and 4375'64 persist in the spectra later than June 15, when the enhanced lines of both iron and titanium have become almost extinct.

Pair of Strong Nova Lines near 4060.

It will be seen from Table I. that the residuals for the two lines whose identity with the abnormal nitrogen lines is in question are of the same order, in the mean, as those for other nitrogen and oxygen lines. The various observers who have drawn attention to this strange pair of lines apparently accept them as being presumably of the same origin, whatever it may be, throughout the series of spectra in which they occur, although varying considerably in position from day to day. If, then, the evidence produced for their identity with the nitrogen lines is satisfactory for any one or more days on which they exist simultaneously with the ordinary nitrogen lines similarly displaced, there is apparently no reason why that identity should not also be accepted for the later dates on which the strong pair is seen while the ordinary nitrogen lines are lacking. There is evidence from normal stellar spectra that these lines sometimes occur unaccompanied by the ordinary nitrogen lines. Thus in 29 Canis Majoris abnormal line 4097.4 is almost as strong as H_{δ} , which probably masks the other component of the nitrogen pair, but, judging from Miss Cannon's* list of lines for 29 Canis Majoris, the ordinary lines of nitrogen are entirely lacking.

In Table II. the measured and corrected wave-lengths for the two strange lines are given for June 15, 17, 18, 19, 20, 21, 22. These are the only dates of the Victoria series on which the abnormal nitrogen lines and the ordinary lines of nitrogen and oxygen occur simultaneously. For plates later than June 22 there is, then, no guide as to what the displacement really is for the two lines in question, except on the assumption that in these later spectra they are also identical with the abnormal nitrogen lines.

Lunt specially refers to the strong nova pair for July 2, 15, where the velocity displacements, assuming the lines to be the nitrogen lines 4097, 4103, are -3432 km./s. and -3167 km./s. respectively. These are considerably higher velocities than those obtained from the nitrogen and oxygen lines on dates from June 15-22, when the velocity varied from -2694 to -2907 , which two extremes, however, occur on successive days. But if velocity be the real explanation of the spectrum shifts, we have evidence from the nova that the range in velocity of hydrogen vapour is between -1456 km./s. for the first displacement on June 10, to -2278 km./s. for the second displacement on June 15, *i.e.* a range of 815 km./s., so the range for nitrogen lines of 738 km./s. from the -2694 of June 17 to the -3432 of July 2 cannot be rejected as either excessive or impossible. The last-mentioned displacement is that estimated by Lunt, on the assumption that the nova pair is identical with the nitrogen pair. This value seems to be considerably too high. The measured wave-length for the mean of the nova pair on this date, as recorded by both Paddock and Harper, is 4057. From my measures on Plaskett's

* *Ann. Harv. Coll. Obs.*, 28, 233.

plate it is 4056.0. Lunt records it as 4055. The difference between the mean of the first three estimates and that of Lunt represents a difference in velocity of 120 km./s. There can be no doubt, however, that there is a general tendency for the nova pair to drift out to the violet in passing from the earlier to the later nova plates, but this drift is by no means uniform.

TABLE II.

Measured and Corrected Wave-Lengths of Pair of Nova Lines near 4060.

Date.	Measured λ .	Velocity in km./s. from N and O Lines (Disp. 1).	λ Correction for Velocity Shift.	Corrected λ .	λ of Laboratory Line.	Estimated minus Tabular λ .	No. of Lines used for Estimation of Velocity.
June 15	4060.78 } 4065.73 }	-2749	+37.56 37.61	4098.34 4103.34	4097.43 4103.46	+ .91 - .12	6
17	4060.75 } 4066.62 }	2694	36.81 36.86	4097.56 4103.48	4097.43 4103.46	+ .13 + .02	7
18	4057.87 } 4064.28 }	2907	39.73 39.78	4097.60 4104.06	4097.43 4103.46	+ .17 + .66	7
19	4059.28 } 4065.61 }	2865	39.16 39.21	4098.44 4104.81	4097.43 4103.46	+ 1.01 + 1.35	7
20	4059.66 } 4066.34 }	2875	39.30 39.35	4098.96 4105.69	4097.43 4103.46	+ 1.53 + 2.25	5
21	4057.80 } 4064.56 }	2903	39.68 39.73	4097.48 4104.29	4097.43 4103.46	+ .05 + .83	4
22	4058.13 } 4064.13 }	2889	39.48 39.53	4097.61 4103.66	4097.43 4103.46	+ .18 + .20	4

Mean Difference in λ (Estimated - Tabular) = 0.66 tenth-metre.

In Table II. the results are based solely on my measures of Plaskett's plates. It has been thought advisable, however, to apply the same estimated correction for velocity to the *mean* measures for the nova pair, as obtained from the records of various observers.

In Table III., columns 2 to 6, are given the wave-lengths of the middle of the nova double (in its collective aspect) as recorded by Harper, Lunt, Paddock, Evershed, and myself. The figures for the first four observers are taken from Lunt's last paper. Column 7 gives for each day the means of the individual estimates of the five observers. Column 8 gives the velocity estimated by the author for each day from selected N and O lines on Plaskett's plates. Column 9 gives the corresponding wave-length correction, to be applied to the measured wave-lengths. The last column gives the normal wave-lengths for the middle of the nova pair, on the assumption that it is subjected to the same velocity displacement as the ordinary lines of nitrogen and oxygen.

TABLE III.

Mean Measured Positions of Pair of Dark Lines near 4060
(bisected as one line).

Date.	Harper.	Lunt.	Paddock.	Ever-shed.	Baxandall.	Mean λ (Five Observers).	Velocity for Disp. 3, from Selected N and O Lines (in km./s.).	Corresponding λ Shift for Line at 4100'44. (Mean of N { 4097'43 4103'46).	Corrected λ .
June 15	...	...	4062	...	4063'3	4062'65	- 2749	- 37'59	4100'2
17	4064	4063	...	...	4063'7	4063'57	2694	36'84	4100'4
18	4063	4062	4062	4062	4061'3	4062'06	2907	39'75	4101'8
19	4062	...	4063	4059	4062'5	4061'62	2865	39'18	4100'9
20	4065	...	4062	4062	4063'0	4063'00	2875	39'31	4102'3
21	...	4062	4061	...	4061'2	4061'40	2903	39'61	4101'0
22	..	4062	4061	...	4061'1	4061'37	2889	39'50	4100'8

Mean corrected λ of middle of nova double = 4101'08.

Mean λ of pair of abnormal N lines = 4100'44.

Difference = 0'64 tenth-metre.

The difference between the calculated mean λ of the pair of nova lines (after the velocity correction for displacement 3) and the wave-length of the middle of the pair of abnormal nitrogen lines in laboratory spectra may appear rather large, but it probably comes within the error of measurement of such vague and indefinite lines. In this connection a glance at Table III. will show that the estimated mean positions of the two nova lines (sometimes seen as one broad line) by different observers on the same day vary in some cases as much as 4 tenth-metres.

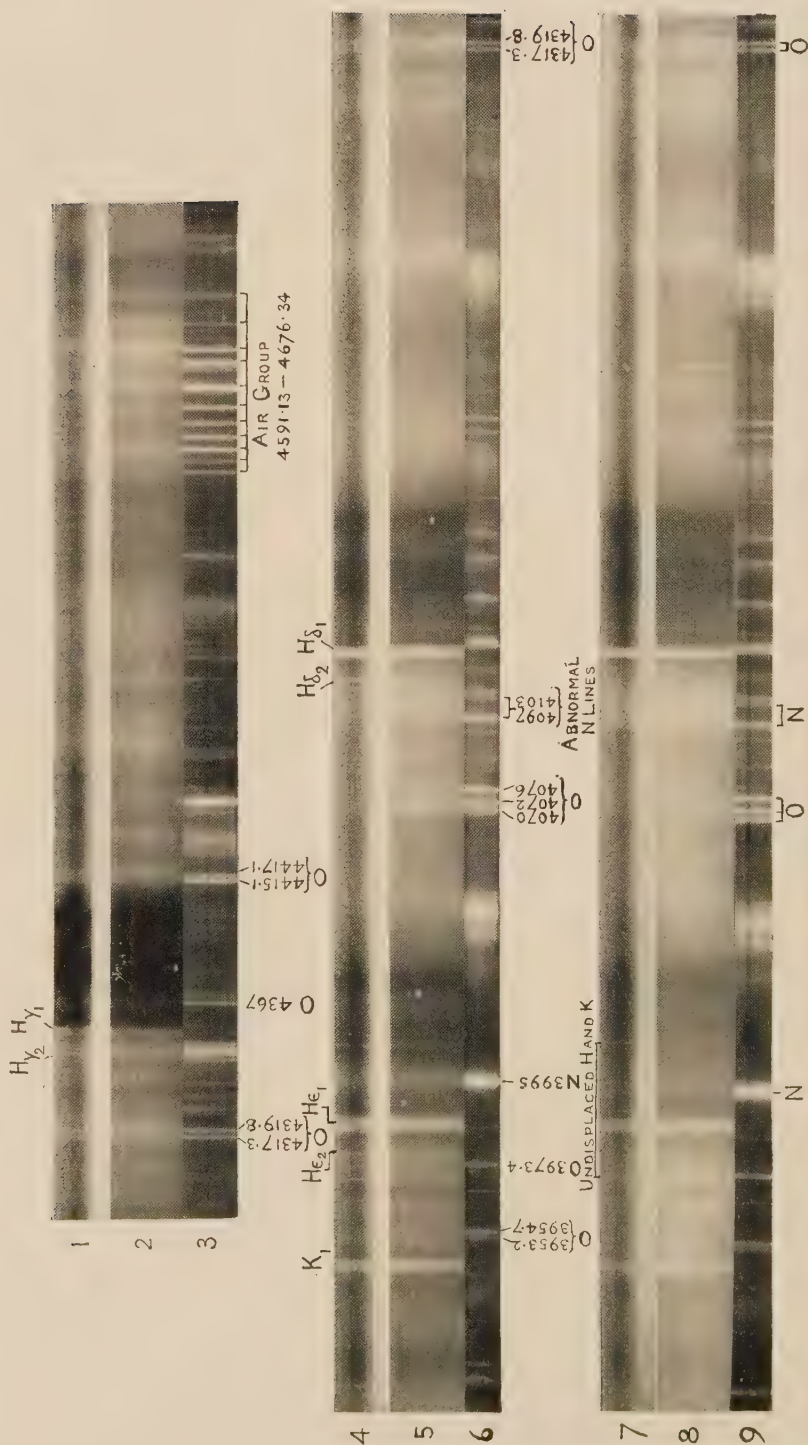
The resulting normal wave-length (4101'08) for the mean of the two nova lines is so near the wave-length of H_{δ} that it is natural to suggest that the nova double may really be a double H_{δ} line with the mean velocity corresponding to that obtained from various nitrogen and oxygen lines. But as there are no corresponding lines for H_{γ} or H_{β} , or, in fact, for any other hydrogen line, the identity with H_{δ} cannot be upheld. The elements whose lines are subjected to this third displacement appear to be confined to nitrogen, oxygen, helium, and carbon.

Note on Abnormal Nitrogen Line 4379'8.

Although the presence of 4379'8 in the nova spectra would strengthen the evidence for the identity of the other nitrogen lines with the nova lines, the absence of 4379'8 in the same spectrum cannot be accepted as an argument against such identity. Although 4097'4 and 4379'8 are both nitrogen lines of abnormal behaviour, they do not strengthen and weaken together in laboratory spectra. As Lunt points out,* "stellar spectra indicate that this line (4097) may stand alone as the evidence of nitrogen at high temperatures." In 29 Canis Majoris, where it is very strongly represented, the only other evidence for nitrogen seems to be a line at 4514'5, which can be ascribed to another abnormal line of nitrogen recently traced by Fowler.

* M.N., R.A.S., 80, 534.

Absorption Lines of Nitrogen and Oxygen in Spectra of Nova Aquilæ III.



KEY TO PLATE.

1. Nova Aquilæ, June 15 (Region 430-470). Directly enlarged.
2. Same spectrum, artificially widened.
4. Nova Aquilæ, June 15 (Region 390-432). Directly enlarged.
5. Same as 4, but artificially widened.
7. Nova Aquilæ, June 18 (Region 390-432). Directly enlarged.
8. Same as 7, but artificially widened.
- 3, 6, and 9. Air spectrum enlarged approximately to same scale as nova spectra.

(Nova spectra are negative prints from Plaskett's positives.
Air spectra are positives.)

Reference to Plate.

In a preliminary survey of Plaskett's spectra, enlargements on paper were made from the nova plates, as well as enlargements—to approximately the same scale—of various spectra of the normal stellar types and of laboratory spectra. Amongst the latter were spectra of nitrogen and oxygen, which had been obtained with various spectrographs. It was expected that there would be considerable difficulty in getting an exact fit between the nova and laboratory spectra, owing to the different dispersion in various parts of the spectrum. It was found, however, that the laboratory spectra photographed with two 6-inch Henry prisms could be enlarged so as to give almost an exact fit throughout the whole length of spectrum. An enlargement of the air spectrum taken with these prisms has therefore been used in the plate alongside the nova spectrum, so that the identical lines in the two spectra can be seen at a glance. The difficulty of getting an exact fit is further complicated by the nova lines having varying linear shifts owing to velocity, or whatever the real cause may be. More weight can be given, in an attempt to establish the identity of the laboratory and nova lines, to the actual measures and reductions, but the confronting of the two spectra is of great assistance, the distinctive grouping of the lines catching the eye. This is particularly noticeable in the well-known group of strong air lines $\lambda\lambda$ 4591-4676. For a description of the plate, the text below it is deemed sufficient.

I wish to express my thanks for the great assistance rendered by Mr. W. H. Manning in the preparation of the photographs for reproduction.

Further Note on Barnard's Observations of Variable Bailey No. 33 in the Cluster M5, with a suggestion that the Comparison Star k is a Short-period Variable. By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

1. Professor Barnard has kindly sent me his observations for 1920, which show that the change of period in 1919, suspected in my former paper (*M.N.*, 80, 640), is not confirmed. He also corrects the misconception embodied in a terminal note to that paper. Comparison of the variable with the star *k* both on the rise and fall is theoretically possible, but practically it would be difficult to make both observations on the same night; at any rate, Barnard has not done so—his observations refer consistently to the rise only, so that the variability of *k* is an open question so far as Barnard's observations are concerned, and any change in the star *k* would influence the apparent period of the variable.

2. Barnard was perturbed by this possibility of the variation of *k*, and wrote to Mount Wilson asking whether they had photographs which might test the matter. On July 5 last he was able to send me the valuable series of observations given in Table II., which make it clear that the suggested variation of *k* is in any case small. I have collected Barnard's observations of Bailey 33 in Table I., comparing them with three adopted periods, $0^d.50147330$ for 1899 to 1903, $0^d.50147396$ from 1904 to 1913, and $0^d.50147130$ from 1915 to 1920. Some of these observations have been published in *A.N.*, 4409, 4584 (where an error is corrected), and 4681.

3. In Table I. the first column gives the Julian Day (omitting the constant 2410000 or 2420000) and fractions in G.M.T. (In some of his papers Barnard has used a time 6 hours or 0.25 day different from this.)

The second column gives the multiple of the period $0^d.50147330$ nearest to the first column: and the third column gives the difference (in units of 0.000001 day) between Barnard's date and the precise multiple C_1 . The value of C_1 can be recovered, if required, by subtracting $O - C_1$ from the first column. Thus for the multiple 12300 the value of C_1 is $2420990.81035 - .00095 = 2420990.80940$, which differs from the zero multiple $2414822.68863 - .00082$ or 2414822.68781 by $6168.12159 = 12300 \times .50147330$.

In the fourth and fifth columns two changes of period are suggested, one near 2416500 (1904), and one near 2420000 (1914). The first is an increase of $0^d.00000066$, which in the 6521 cycles given in the table accumulates to $0^d.00430$ or 6.2 minutes: the second is a decrease of $0^d.00000200$, which in the 3715 cycles tabulated accumulates to $0^d.00743$. The zero-point is in each case assigned arbitrarily from the general run of the numbers.

The last two columns will be referred to later.

TABLE I.

Barnard's Dates (G.M.T.) for Equality of Bailey 33 with k.

Julian Date.	Mult.	O - C ₁ .	Corr.	O - C ₂ .	Mult.	k.
4822.68863	0	+ 82	0	+ 82	0	'07023
4830.71071	16	- 68	0	- 68	15	'37076
4831.71417	18	- 16	0	- 16	17	'34468
5174.72208	702	+ 2	0	+ 2	684	'00100
5175.72500	704	- 1	0	- 1	685	'48915
6204.74750	2756	- 72	0	- 72	2684	'48642
6209.76375	2766	+ 80	0	+ 80	2694	'35497
6211.76875	2770	- 9	0	- 9	2698	'30089
6671.62042	3687	+ 56	+ 86	+ 142	3591	'46295
6678.63875	3701	- 174	+ 86	- 88	3605	'27450
8065.71833	6467	+ 270	- 97	+ 173	6300	'04893
8081.76083	6499	- 195	- 98	- 293	6331	'13356
8084.77207	6505	+ 46	- 99	- 53	6337	'05618
8088.78514	6513	+ 173	- 100	+ 73	6344	'46586
9229.63778	8788	+ 261	- 250	+ 11	8561	'07341
9234.65201	8798	+ 211	- 251	- 40	8570	'45471
9239.66743	8808	+ 280	- 251	+ 29	8580	'32243
9243.67854	8816	+ 212	- 252	- 40	8588	'21538
9929.69576	10184	+ 386	- 342	+ 44	9921	'04419
9931.70257	10188	+ 478	- 343	+ 135	9924	'50669
9940.72685	10206	+ 254	- 344	- 90	9942	'26511
9941.73160	10208	+ 435	- 344	+ 91	9944	'24032
0630.75229	11582	+ 73	- 183	- 110	11282	'49875
0990.81035	12300	+ 95	- 40	+ 55	11982	'21781
0994.82195	12308	+ 76	- 38	+ 38	11990	'11125
1340.83645	12998	- 132	+ 100	- 32	12662	'20031
1345.85360	13008	+ 110	+ 102	+ 212	12672	'06976
1784.63896	13883	- 268	+ 277	+ 9	13524	'27108
1786.64444	13887	- 309	+ 277	- 32	13528	'21748
2127.64590	14567	- 347	+ 413	+ 66	14190	'44120
2131.65660	14575	- 456	+ 415	- 41	14198	'33374
2138.67743	14589	- 436	+ 418	- 18	14212	'14779
2141.68945	14595	- 118	+ 419	+ 301	14218	'07119
2143.69375	14599	- 277	+ 420	+ 143	14222	'01641
2481.68363	15273	- 589	+ 555	- 34	14878	'31717
2484.69250	15279	- 586	+ 556	- 30	14884	'23742
2486.69868	15283	- 557	+ 556	- 1	14888	'18452
2488.70313	15287	- 701	+ 557	- 144	14892	'12989
2491.71403	15293	- 495	+ 559	+ 64	14898	'05217
2493.71958	15297	- 529	+ 560	+ 31	14901	'51341

4. Having studied the column O - C₂, I could not help feeling that—

- (a) the two changes of period were satisfactorily established by the improved character of the residuals;
- (b) yet some of the residuals were too large to do justice to the observing. Inquiry from Barnard brought to light no accidental errors of transcript or reduction.

5. Hence I cast about for some evidence of a systematic character, and after various trials hit upon a period of about 38.6 multiples of the period (*i.e.* about 193 days) in which the positive and negative residuals seemed to be consistently grouped. Was this an actual period of variation or a period of "interference"? And was the variation in Bailey 33 or in the comparison star *k*? If the period was one of "interference," then the actual period of variation could be any submultiple

$$0.50147 \times 38.6 / (38.6 \pm n)$$

where *n* is an integer. Now one tempting possibility was that *k* was a variable of much the same period as Bailey 33, but with a small range. In that case *n* would be a small integer, and the Mount Wilson observations might suffice, with this clue, to reveal the period. The trial of *n* = +1 gave a small and smooth variation of *k* with which I was about to be content, but as a check I tried what would happen with *n* = -1, and to my surprise found a far more decided variation with a sudden rise to maximum, similar to that of Bailey 33.

6. With this clue it is not difficult to see this sudden rise by inspection of the Mount Wilson observations given in Table II., though I had not remarked it before. There are sudden rises at dates (approximately)

Dates.	Differences.
339.745	$36.052 = 70 \times .5150$
375.797	$48.891 = 95 \times .5146$
424.688	$2.098 = 4 \times .524$
426.786	

A series of trials on the Mount Wilson direct observations and on Barnard's residuals provisionally gave the period as 0^d.514770. The "interference" is thus represented by the equivalence

$$38.713 \times .501473 = 37.713 \times .514770.$$

7. Adopting this period, the Mount Wilson observations are arranged in Table III. according to the fraction of a day as counted from 339.600.

TABLE II.

Mount Wilson Photographic Observations of Bailey 33 and the Comparison Star k.

Julian Date.	33.	k.	Julian Date.	33.	k.
339'698	15'45	15'41	424'679	15'09	15'48
'721	'61	'44	'698	'18	'31
'767	'52	'22	'717	'23	'35
'828	15'16	'34	'734	'18	'35
'849	14'54	'24	'749	'10	'14
'869	'72	'34	'770	'27	'37
'890	'81	'30	'786	'30	'35
'912	14'70	'40	'804	'43	'31
'934	15'14	'44			
'956	14'99	'27	425'680	15'04	15'36
'974	15'17	'49	'698	14'90	'39
'994	'18	'33	'714	15'01	'41
340'011	'16	'25	'736	'12	'39
'016	'36	'32	'752	'27	'32
			'773	'30	'35
375'718	15'57	15'32	'795	'35	'32
'767	'76	'43			
'827	'34	'23	426'706	15'02	15'22
'845	'50	'24	'722	'06	'28
'862	'49	'23	'760	'21	'27
'886	'46	'26	'778	'27	'42
'906	'64	'32	'794	'27	'27
'927	15'30	'33	'802	'26	'26
'947	14'76	'35	'811	'37	'27

In order to get a smooth curve, the means of every five consecutive terms were taken, as shown in the third and fourth columns of Table III.; and from them it was easy to draw a curve showing the main variation as in the fifth column.

8. But on comparing this, even with the smoothed means as in the column headed O - C, it is seen that the differences show fluctuations of a fairly regular character. There are minima (algebraically) about 110, 164, 212, 269. Now, whatever the period of this smaller fluctuation may be, it must be an exact submultiple of the main period; otherwise, in combining the different plates as we have done, we should have wiped it out. From the Mount Wilson observations alone it is not easy to identify the submultiple, since they only extend over a portion of the main period, the interval 0'084 to 0'416, or 0'332, being considerably less than 0'515. We will reserve further study of it until we have reviewed Barnard's residuals.

TABLE III.

Mount Wilson Observations of Comparison Star k arranged in a Period of $0^d.5147700$, counting from 339.600. The dates are in 0.001 of a day, and the magnitudes in 0.01 magnitude fainter than 15.00.

Date.	Mag.	Means of 5.			
		Date.	Mag.	Curve.	O - C.
084	32				
098	41				
110	22	105	35	38	-3
113	36	114	34	38	-4
121	44	120	34	38	-4
126	28	125	38	38	0
131	39	131	40	38	+2
133	43	136	40	38	+2
142	48	143	40	38	+2
147	41	149	38	37	+1
161	31	156	34	36	-2
164	27	162	32	35	-3
167	22	168	31	34	-3
169	39	172	33	33	0
180	35	176	34	33	+1
182	42	182	34	32	+2
185	32	187	33	31	+2
193	23	190	32	30	+2
197	35	196	29	30	-1
198	27	200	29	29	0
206	26	204	29	28	+1
206	35	207	25	28	-3
211	24	210	25	28	-3
212	14	215	25	27	-2
215	27	219	24	26	-2
228	23	222	26	27	-1
228	32	226	31	28	+3
228	34	233	30	29	+1
233	37	237	32	30	+2
249	24	242	31	30	+1
249	35	250	31	31	0
252	26	257	30	32	-2
267	31	262	32	32	0
269	34	270	31	32	-1
272	32	278	32	33	-1

TABLE III.—*continued.*

Date.	Mag.	Means of 5.			
		Date.	Mag.	Curve.	O - C.
290	30	287	34	34	0
293	33	296	34	34	0
312	40	308	36	35	+1
313	35	322	36	35	+1
334	44	338	39	36	+3
356	27	354	38	36	+2
374	49	374	36	37	-1
394	33	390	33	37	-4
411	25				
416	32				

9. Returning now to Table I., in the seventh column, under heading k , is given the time elapsed at Barnard's comparison (first column) since the last completed multiple of $0^d.5147700$, the number of the multiple being shown in the sixth column. Thus the zero multiple for k is

$$4822.68863 - .07023 = 4822.61840,$$

and multiple 6300 is at

$$8065.71833 - .04893 = 8065.66940,$$

the interval between being

$$3243.05100 = 6300 \times .5147700.$$

10. Barnard's residuals $O - C_2$ were then arranged (in Table IV.) according to this phase of k , which is given in the first column. On taking means of 5 it was seen that the *principal* features could be represented by two straight lines joining the points

$$k = .07000 \quad O - C_2 = +90$$

$$k = .12000 \quad O - C_2 = -96.$$

11. This solution is given under the heading C_3 : but it will be seen from the column headed $O - (C_2 + C_3)$ that it is not the *complete* solution. There are well-marked waves, suggesting that the third harmonic is large: and on studying these waves we can again trace their division into three. The ninth harmonic is probably the feature already noticed in the Mount Wilson observations. It is, however, doubtful whether it is advisable to attempt to specify these terms precisely from the present material, which is affected by too many uncertainties, especially the three adopted periods of Bailey 33 in Table I. By altering these a little, the end residuals of each set can be altered considerably. Moreover, if we substitute in Table I. the new residuals $O - (C_2 + C_3)$, we find marked indications that revision of periods is needed. The possi-

TABLE IV.

Barnard's Residuals in Period of $0^d.5147700$ for k .

k .	$O-C_2$.	C_3 .	$O-(C_2+C_3)$.	k .	$O-C_2$.	C_3 .	$O-(C_2+C_3)$.
001	+ 2	+62	- 60	240	+ 91	-48	+139
016	+143	+68	+ 75	265	- 90	-38	- 52
044	+ 44	+80	- 36	271	+ 9	-36	+ 47
049	+173	+82	+ 91	275	- 88	-35	- 53
052	+ 64	+83	- 19	301	- 9	-24	+ 15
056	- 53	+85	-138	317	- 34	-17	- 17
070	+212	+90	+122	322	+ 29	-15	+ 44
070	+ 82	+90	- 8	334	- 41	-10	- 31
071	+301	+86	+215	345	- 16	- 6	- 10
073	+ 11	+80	- 69	355	+ 80	- 2	+ 82
111	+ 38	-62	+100	371	- 68	+ 4	- 72
130	-144	-92	- 52	441	+ 66	+32	+ 34
134	-293	-90	-203	455	- 40	+38	- 78
148	- 18	-85	+ 67	463	+142	+41	+101
185	- 1	-70	+ 69	466	+ 73	+42	+ 31
200	- 32	-64	+ 32	486	- 72	+50	-122
215	- 40	-58	+ 18	489	- 1	+52	- 53
217	- 32	-57	+ 25	499	-110	+56	-166
218	+ 55	-56	+111	507	+135	+58	+ 77
237	- 30	-49	+ 19	513	+ 31	+61	- 30

bility of obtaining greater precision at once was not forgone without trial: a good deal of work was, indeed, done in this direction, but ultimately torn up.

12. Two important points, however, deserve some notice.

(a) If there is, indeed, a small fluctuation in one-ninth of the main period, it would afford a parallel to a suggestion received from Professor Dinsmore Alter of Kansas. By a somewhat strange coincidence, Professor Alter's paper suggesting a period in sunspots of one-ninth the main period reached me on the very day on which I had first been led to suspect this one-ninth harmonic in the variation of k . There seems to be some evidence for the sunspot fluctuation, which will be presented in due course; but I have hitherto failed to find any case of a similar fluctuation among variable stars with the possible exception of Bailey 33 itself. Barnard's observations of this star are all made close to one phase, and therefore give us no information about the light curve: but the Mount Wilson observations give some evidence of a fluctuation in $0^d.0557 = .5015/9$ day. The observations are, however, not well enough distributed over the main light curve to establish the variation. They are collected according to the main phase in Table V.

TABLE V.

Mount Wilson Observations of Bailey 33 (magnitude in units of 0.01: phase counted from 339.600).

Phase.	Mag.	Curve.	O - C.	Phase.	Mag.	Curve.	O - C.
012	157	160	- 3	356	99	102	- 3
061	176	158	+ 18	362	101	103	- 2
098	145	157	- 12	367	106	107	- 1
121	161	155	+ 6	368	123	107	+ 16
121	134	155	- 21	374	117	110	+ 7
139	150	153	- 3	384	112	112	0
156	149	153	- 4	385	118	112	+ 6
167	152	152	0	394	118	118	0
180	146	152	- 6	400	110	120	- 10
200	164	150	+ 14	400	127	120	+ 7
221	130	120	+ 10	405	121	122	- 1
228	116	105	+ 11	411	116	124	- 8
241	76	76	0	416	136	126	+ 10
249	54	56	- 2	421	127	128	- 1
269	72	65	+ 7	421	130	128	+ 2
290	81	73	+ 8	423	127	129	- 2
312	70	83	- 13	437	130	133	- 3
328	104	90	+ 14	439	127	134	- 7
329	109	91	+ 18	443	135	136	- 1
334	114	93	+ 21	447	126	138	- 12
346	90	98	- 8	455	143	140	+ 3
349	118	100	+ 18	456	137	140	- 3
351	102	101	+ 1				

The magnitudes are counted from 14.00. Thus 157 means $14.00 + 1.57 = 15.57$.

Now from phase .000 to .167 (the first third of the cycle) there are only 5 records: in the next third (to .334) there are only 11, while 29 fall in the last third. Moreover, the middle third is disturbed by the rapid rise to maximum. Hence, though a diagram suggests sensible terms of one-third and one-ninth the main period, further observations are required to establish them.

(b) The figures headed "Curve" in Table V. are taken from a diagram consisting of three straight lines, the most important of which represents the sudden rise from 150 (or mag. 15.50) at phase $339.600 + .200 = 339.800$ to 56 (or mag. 14.56) at phase $339.600 + .249 = 339.849$. It so happens that the preceding figures of the Julian Day (whether 2422000 or 2421000, etc.) were omitted, either in transcribing from the Mount Wilson documents (now returned) or possibly in the documents themselves: but

this date of maximum enables us to recover them from Barnard's observations, which assign dates of maximum (following the equality with k by $30^{\text{min.}} = 0^{\text{d}}.021$) at 2339.794, 1339.856, 0339.918, 9339.980, etc. It seems pretty clear that the second of these is the right one, showing that the Mount Wilson plates were taken in 1917.

The maximum brightness of k will be represented in Barnard's observations by the largest positive residual (since Bailey 33 required more time to catch up k), which in Table IV. falls at .070. Now Table I. shows a zero epoch to be

$$1340.83645 - .20031 = 1340.63614;$$

or, subtracting $2 \times .51477$, we get 1339.60660, so that the maximum of k according to Barnard falls at 1339.67660. Now, referring to Table III., we see that this is outside the range of the Mount Wilson observations, the earliest of which is at 1339.684; so that the Mount Wilson maximum at 1339.819 must be something quite different. It follows Barnard's maximum by 0.142 day = 3.4 hours, a quite unmistakable quantity. In Table IV. the Mount Wilson maximum would fall at 0.212, and we see that in this neighbourhood there is a batch of positive residuals in the column $O - (C_2 + C_3)$ representing a secondary maximum, preceding which there is a sharp rise. We may identify this rise in the two cases as follows:—

	Begins.	Ends.	Low.	High.
Mt. Wilson, Table III. } Corrected to Barnard's Epoch. }	.143	.219	40	24
Barnard's Table IV. }	.136	.212		
	.134	.218	-293	+55

The Mount Wilson rise in magnitude is 0.16. Now at the epoch of comparison Bailey 33 changes 0.93 mag. in 30 minutes (according to Barnard's diagram in *A.N.*, 4409), or 0.1 mag. in .0022 day. Hence to change 0.16 mag. it takes .00352 day. The figures quoted, -293 to +55, give a rise of .00348 day, but they cannot be taken so seriously as this. They only serve to show that we have a difference of about the right order, and that the -293 residual, excessive as it looks, may be real.

Summary.

1. Barnard's comparisons of Bailey 33 with star k from 1899 to 1920 show two distinct changes of period (in 1904 and 1914). What follows leaves this statement practically untouched (see § 2).

2. But they also show that the comparison star k varies in a period of 0.514770 day, the main feature of which is a sharp fall of about 0.25 mag. in brightness in about 0.06 day = 1.5 hours,

followed by a general rise to maximum for 10 hours. The sharp fall is, however, followed by a comparatively sharp rise to a secondary maximum.

3. Some Mount Wilson photographic observations in 1917 confirm this secondary maximum with sharp rise: but the principal maximum and sharp fall after it lie unfortunately outside the range of the Mount Wilson plates. It is much to be desired that more plates of the same kind shall be taken covering this feature in the variation of k . The critical times are from

$$2421339.640 \text{ to } .840(+0.514770n),$$

or say

$$2422883.950 \text{ to } .150(+0.514770n).$$

4. The Mount Wilson observations further suggest a rapid fluctuation in one-ninth of the main period, with which Barnard's comparisons are consistent, though they scarcely suffice to establish it. Continued observations of both stars, both visual and photographic, are much to be desired.

Observations of Minor Planets made with the 10-inch Refractor of the University Observatory, Utrecht, Holland. By J. van der Bilt.

Date.	Utrecht Mean Time.			App. R.A.			Log. Parallax Factor.	App. Decl.			Log. Parallax Factor.	No. of Obs.	Comp. Star.
1920	h	m	s	h	m	s		°	'	"			
(3) <i>Juno</i> .													
Apr. 22	13	50	34	14	23	5.34	9.142	-	0	39	10.9	0.844	6, 3 1
23	11	37	53	14	22	22.02	8.771 _n	-	0	33	21.0	0.844	6, 3 2
25	12	26	41	14	20	44.35	8.510	-	0	20	37.3	0.843	6, 6 3
27	11	43	22	14	19	10.08	9.555 _n	-	0	8	38.5	0.842	6, 3 4
May 3	12	7	14	14	14	25.00	8.786	+	0	25	1.7	0.839	10, 5 5
4	13	5	8	14	13	36.59	9.199	+	0	30	24.9	0.839	4, 2 6
4	13	7	35	14	13	36.99	9.199	+	0	30	20.0	0.839	6, 3 7
10	12	52	46	14	9	2.46	9.247	+	0	58	10.7	0.836	6, 3 8
11	11	8	46	14	8	29.09	8.449	+	1	1	55.0	0.834	8, 4 9
13	12	21	51	14	7	3.24	9.181	+	1	9	59.2	0.835	12, 4 10
14	12	48	57	14	6	21.80	9.291	+	1	13	43.3	0.834	6, 3 10
15	10	45	54	14	5	45.03	8.327	+	1	16	54.5	0.834	6, 6 11
16	11	29	39	14	5	4.66	8.983	+	1	20	20.5	0.833	4, 2 11
21	11	44	40	14	2	0.27	9.181	+	1	35	43.8	0.752	6, 3 11
27	10	47	5	13	58	52.90	9.027	+	1	46	32.1	0.831	6, 3 12
28	11	13	25	13	58	24.35	9.196	+	1	47	39.6	0.831	6, 3 12
31	10	28	15	13	57	7.71	9.019	+	1	50	35.6	0.830	8, 4 13

Date.	Utrecht Mean Time.			App. R.A.			Log. Parallax Factor.	App. Decl.	Log. Parallax Factor.	No. of Obs.	Comp. Star.
1920.	h	m	s	h	m	s	° ' "				
(4) <i>Vesta</i> .											
May 21	14	15	5	18	7	45.51	7.910	-17 55 29.7	0.917	6, 3	14
28	13	46	52	18	3	20.68	8.316	-18 13 39.3	0.918	12, 3	15
June 8	13	32	8	17	53	54.97	8.886	-18 49 25.1	0.828	6, 3	16
30	11	7	31	17	32	4.16	8.235	-20 16 41.6	0.923	2, 1	17
(8) <i>Flora</i> .											
Jan. 21	12	29	47	6	22	36.06	9.627	+22 40 30.1	0.666	6, 3	18
23	11	5	44	6	21	5.89	8.947	+22 50 3.8	0.639	6, 3	18
Feb. 3	13	0	31	6	15	42.97	9.502	+23 31 42.5	0.707	6, 3	19
4	13	38	50	6	15	27.65	9.550	+23 36 17.6	0.735	4, 2	20
5	12	35	58	6	15	15.67	9.478	+23 39 37.8	0.706	6, 3	20
22	11	40	40	6	17	32.51	9.496	+24 27 49.4	0.694	6, 3	21
26	11	45	4	6	19	35.77	9.520	+24 36 25.0	0.705	6, 3	22
27	12	36	31	6	20	12.49	9.572	+24 38 28.1	0.745	8, 4	23
Mar. 1	11	43	33	6	22	9.59	9.535	+24 43 57.8	0.713	12, 4	24
3	10	42	7	6	23	35.29	9.833	+24 47 18.9	0.674	12, 4	25
22	9	20	40	6	42	32.70	9.403	+25 4 58.6	0.655	16, 4	26
Apr. 10	11	11	27	7	8	45.12	9.591	+24 53 33.7	0.769	8, 4	27
16	11	21	42	7	18	1.44	9.597	+24 43 18.3	0.787	6, 3	28
21	10	39	28	7	25	58.69	9.587	+24 32 30.9	0.762	12, 6	29
23	9	50	7	7	29	11.00	9.561	+24 27 37.7	0.734	6, 3	30
(10) <i>Hygiea</i> .											
Jan. 14	12	1	7	4	45	9.07	9.423	+24 13 31.6	0.670	6, 3	31
16	12	29	25	4	44	17.80	9.489	+24 9 41.1	0.694	6, 6	31
21	11	20	28	4	42	35.30	9.394	+24 0 52.8	0.666	6, 3	32
23	11	46	4	4	42	3.43	9.466	+23 56 41.1	0.687	6, 3	32
Feb. 22	10	19	26	4	44	59.12	9.508	+23 31 5.9	0.710	6, 3	33
(12) <i>Victoria</i> .											
Feb. 23	11	4	29	8	42	50.90	8.698	+5 17 15.8	0.807	8, 4	34
26	13	22	54	8	40	20.53	9.416	+5 33 12.2	0.815	3, 3	35
28	12	1	3	8	38	45.78	9.231	+5 43 12.8	0.808	4, 2	35
(24) <i>Themis</i> .											
May 14	11	37	49	13	32	46.42	9.165	-9 40 4.3	0.884	6, 3	36
16	10	53	6	13	31	48.58	8.965	-9 35 0.8	0.887	12, 6	37
(25) <i>Phocæa</i> .											
May 28	11	41	12	15	6	42.43	8.991	-1 7 50.5	0.848	10, 5	38
June 3	11	13	34	15	2	39.46	8.961	+0 14 45.8	0.840	12, 6	39

Date.	Utrecht Mean Time.	App. R.A.	Log. Parallax Factor.	App. Decl.	Log. Parallax Factor.	No. of Obs.	Comp. Star.
1920	h m s	h m s		° ' "			
(39) <i>Laetitia</i> .							
Jan. 14	13 23 52	8 28 29.50	8.650	+ 9 51 24.8	0.772	6, 3	40
16	12 6 32	8 26 51.15	8.801 _n	+ 10 1 9.0	0.820	6, 3	41
21	11 54 47	8 22 32.81	8.644 _n	+ 10 27 54.3	0.767	6, 3	42
23	11 21 38	8 20 48.49	8.908 _n	+ 10 40 0.2	0.766	6, 3	43
Feb. 5	13 45 40	8 9 39.84	9.363	+ 11 57 2.8	0.772	6, 3	44
6	14 4 17	8 8 51.94	9.414	+ 12 4 22.7	0.777	6, 3	44
17	10 41 45	8 1 16.19	8.636	+ 13 11 6.8	0.743	6, 3	45
19	14 26 29	8 0 0.97	9.526	+ 13 23 55.8	0.794	4, 2	45
22	12 56 1	7 58 28.54	9.425	+ 13 40 54.4	0.723	6, 3	46
28	10 50 11	7 56 4.22	9.124	+ 14 13 35.9	0.739	6, 3	47
Mar. 3	11 12 20	7 54 46.42	9.279	+ 14 34 34.4	0.744	6, 3	48
22	9 54 30	7 54 27.37	9.273	+ 15 53 6.0	0.731	6, 3	49
(51) <i>Nemausa</i> .							
Apr. 21	11 33 57	13 1 28.11	8.690	+ 1 51 1.1	0.829	6, 3	50
22	11 46 8	13 0 46.26	8.876	+ 1 59 29.4	0.829	6, 3	51
23	11 10 28	13 0 7.03	8.428	+ 2 7 27.2	0.828	6, 3	51
25	11 32 12	13 0 10.15	8.862	+ 2 23 0.0	0.827	2, 1	52
27	11 21 11	12 57 36.63	8.856	+ 2 37 37.1	0.825	6, 3	53
May 3	11 41 24	12 54 29.11	9.154	+ 3 15 1.5	0.823	10, 5	54
4	12 46 46	12 54 1.92	9.372	+ 3 20 26.5	0.825	6, 3	55
7	9 57 12	12 52 55.17	7.975	+ 3 34 5.7	0.819	6, 3	55
9	10 24 4	12 52 17.33	8.811	+ 3 42 17.7	0.818	6, 3	56
11	10 50 23	12 51 44.85	9.071	+ 3 49 17.3	0.818	14, 4	56
14	10 37 52	12 51 8.23	9.074	+ 3 57 42.6	0.817	6, 2	56
15	10 11 51	12 50 58.68	8.926	+ 3 59 32.8	0.816	12, 3	57
16	11 12 25	12 50 51.01	9.252	+ 4 1 57.7	0.819	24, 6	57
(63) <i>Ausonia</i> .							
Feb. 24	13 45 9	8 17 4.35	9.510	+ 23 28 8.1	0.711	6, 3	58
(68) <i>Leto</i> .							
Feb. 17	14 52 56	8 27 29.65	9.571	+ 30 36 47.0	0.674	6, 3	59
19	12 59 16	8 25 59.53	9.400	+ 30 37 57.5	0.576	6, 3	59
22	13 40 51	8 23 46.47	9.511	+ 30 38 37.9	0.627	6, 3	60
23	14 52 17	8 23 3.12	9.594	+ 30 38 37.4	0.701	8, 3	60
(97) <i>Clotho</i> .							
Feb. 6	10 37 51	8 39 19.89	8.963	+ 8 25 46.1	0.785	6, 3	61
14	12 53 2	8 33 12.79	9.243	+ 9 49 3.8	0.780	6, 3	62
17	11 33 57	8 31 17.88	8.891	+ 10 19 19.8	0.769	6, 3	63
19	14 16 58	8 30 2.49	9.480	+ 10 41 29.8	0.796	3, 3	64
22	12 33 35	8 28 29.62	9.299	+ 11 10 29.7	0.772	6, 3	65
28	10 30 43	8 26 5.01	8.741	+ 12 5 46.7	0.753	6, 3	66
Mar. 3	11 42 33	8 24 50.60	9.277	+ 12 36 45.5	0.760	12, 4	67

Date.	Utrecht Mean Time.	App. R.A.	Log. Parallax Factor.	App. Decl.	Log. Parallax Factor.	No. of Obs.	Comp. Star.
1920	h m s	h m s					
(127) <i>Johanna</i> .							
Mar. 18	14 17 23	12 3 26.62	9.256	+ 7 40 41.9	0.796	6, 3	68
21	13 55 52	12 0 43.66	9.232	+ 7 49 17.6	0.794	6, 2	69
22	11 6 15	11 59 55.23	8.921 _n	+ 7 51 49.1	0.789	6, 3	69
Apr. 16	11 37 39	11 40 51.10	9.170	+ 8 16 9.8	0.789	8, 3	70
20	13 7 44	11 38 22.12	9.451	+ 8 13 35.0	0.805	6, 3	71
21	11 58 12	11 37 56.42	9.316	+ 8 12 11.4	0.794	6, 3	71
(134) <i>Sophrosyne</i> .							
Feb. 28	11 23 2	8 45 40.38	9.066	+ 26 43 35.4	0.588	12, 4	72
(190) <i>Ismene</i> .							
Mar. 18	12 15 16	10 1 39.55	9.255	+ 9 6 23.8	0.786	12, 3	73
21	13 33 32	10 0 25.12	9.462	+ 9 18 46.2	0.800	6, 3	74
(192) <i>Nausicaa</i> .							
Mar. 22	12 51 54	10 48 41.55	9.271	+ 6 40 5.6	0.803	6, 3	75
24	10 32 17	10 47 7.41	8.014 _n	+ 6 46 10.2	0.796	12, 6	76
29	13 18 14	10 43 13.86	9.415	+ 7 0 44.1	0.808	6, 3	77
Apr. 5	11 15 26	10 38 50.14	9.153	+ 7 15 59.9	0.813	6, 3	78
(275) <i>Sapientia</i> .							
Feb. 23	12 12 16	9 35 47.53	8.880	+ 16 6 56.2	0.716	6, 3	79
28	12 20 42	9 32 1.02	9.101	+ 16 36 56.4	0.715	6, 3	80

Estimates of Brightness.

The magnitudes are given in the scale of the *Bonner Durchmusterung*.

Planet.	Date.	Estimate.	Al. m	Instr.
(3) Juno	Apr. 25	J = +0° 3174	9.5	10-inch
	May 13	+1° 2897) 7 J 1 (+1° 2896	9.4	"
	21	+1° 2885) 2 J 4 (+1° 2886	9.2	"
(4) Vesta	May 28	-17° 5028) 3 V 1 (-17° 5112	5.9	3-inch
	June 8	V about 0 ^m .5 > -18° 4686	5.5	"
(8) Flora	Jan. 21	F = +22° 1327	8.7	"
	23	F 1 > +22° 1327	8.6	"
	23	F = +22° 1327	8.7	10-inch
	Feb. 5	+23° 1286) 3 F 1 (+23° 1305	9.2	"
	Mar. 22	F 1 < +25° 1430	9.6	"
	Apr. 21	F 4 < +24° 1677	9.7	"
(10) Hygiea	Jan. 14	H between +23° 748 and +24° 694	9.30	"
(39) Lætitia	Jan. 21	L between +10° 1800 and +10° 1801	9.25	"
	Mar. 22	L 2 < +16° 1595	9.7	"
(51) Nemausa	Apr. 23	N 1 < +2° 2619	9.6	"
	May 9	+4° 2672) 1 N 2 (+4° 2673	9.4	"
	14	N = +4° 2672	9.4	"
(127) Johanna.	Planet not brighter than 12th magnitude.			
(190) Ismene.	"	"	"	"

Comparison Stars.

No.	Mean R.A.	Red. to Date.	Mean Decl.	Red. to Date.	Reference.
	h m s	s	° ' "	" "	
1	14 22 30.94	+2.95	- 0 43 34.1	- 12.0	A. G. Nic. 3740
2	14 21 10.25	+2.97	- 0 37 40.5	- 12.1	" " 3737
3	14 21 56.83	+2.99	- 0 19 51.6	- 11.9	" " 3739
4	14 18 40.50	+3.00	- 0 16 20.5	- 12.1	" " 3729
5	14 15 21.41	+2.99	+ 0 21 17.4	- 11.7	" " 3717
6	14 12 55.35	+3.01	+ 0 17 42.9	- 11.8	" " 3713
7	14 16 24.20	+3.01	+ 0 32 59.4	- 11.6	" " 3720 (p.m. in decl. applied)
8	14 5 47.83	+3.02	+ 0 50 19.7	- 11.7	A. G. Alb. 4884
9	14 7 43.15	+3.02	+ 1 4 57.6	- 11.5	" " 4896
10	14 6 43.25	+3.01	+ 1 10 39.4	- 11.3	" " 4888
11	14 2 49.46	+2.99	+ 1 20 8.0	- 11.3	" " 4876
12	13 57 5.14	+2.96	+ 1 42 47.3	- 10.6	" " 4838
13	13 57 34.37	+2.94	+ 1 55 51.9	- 10.0	" " 4844
14	18 5 51.77	+3.39	- 17 46 24.7	+ 6.3	" Wash. 6566
15	18 2 59.81	+3.53	- 18 2 11.4	+ 6.4	" " 6534
16	17 51 12.60	+3.79	- 18 47 21.3	+ 6.0	Boss 4521
17	17 31 23.83	+4.06	- 20 19 7.2	+ 5.3	Arg. We. 13488
18	6 21 26.57	+2.60	+ 22 45 57.3	- 7.4	A. G. Berl. B. 2379
19	6 14 27.16	+2.55	+ 23 30 8.9	- 6.7	" " 2301
20	6 14 1.96	+2.54	+ 23 38 8.5	- 6.6	" " 2297
21	6 16 30.72	+2.33	+ 24 32 51.8	- 6.1	" " 2323
22	6 18 14.82	+2.28	+ 24 34 38.8	- 6.3	" " 2338
23	6 19 37.70	+2.28	+ 24 48 12.7	- 6.2	" " 2352
24	6 21 55.52	+2.25	+ 24 48 5.0	- 6.2	" Cbr. E. 3228
25	6 23 22.49	+2.23	+ 24 43 59.4	- 6.3	" Berl. B. 2404
26	6 42 20.89	+1.93	+ 24 55 28.2	- 6.8	" " 2592
27	7 9 33.75	+1.72	+ 24 50 57.6	- 7.7	" " 2842
28	7 16 14.48	+1.63	+ 24 46 51.0	- 7.7	" " 2905
29	7 26 0.66	+1.58	+ 24 31 22.0	- 8.2	B.D. + 24° 1677
30	7 30 9.04	+1.58	+ 24 26 28.0	- 8.3	A. G. Berl. B. 3019
31	4 46 23.22	+2.38	+ 24 9 23.9	- 1.4	" " 1537
32	4 39 31.20	+2.31	+ 23 56 10.5	- 0.9	" " 1509
33	4 43 24.45	+1.85	+ 23 37 38.2	- 1.5	" " 1527
34	8 42 17.67	+2.52	+ 5 20 43.2	- 16.5	Toul. ph. Cl. 66, No. 13
35	8 40 18.01	+2.52	+ 5 34 32.2	- 16.6	A. G. Lpz. ₂ 4771
36	13 35 20.90	+3.08	- 9 42 29.8	- 14.7	" Ott. 4869
37	13 31 41.51	+3.05	- 9 22 34.0	- 14.7	" " 4848
38	15 9 1.62	+3.22	- 1 6 6.9	- 6.7	" Nic. 3886
39	15 3 19.17	+3.20	+ 0 20 10.9	- 6.3	" " 3867
40	8 32 45.78	+2.33	+ 9 56 4.6	- 13.0	" Lpz. ₁ 3476

Comparison Stars—continued.

No.	Mean R. A.	Red. to Date.	Mean Decl.	Red. to Date.	Reference.
	h m s	s	° ' "0	"	
41	8 27 33.85	+2.38	+10 5 8.0	-13.2	A. G. Lpz. ₁ 3435
42	8 22 7.03	+2.46	+10 20 35.1	-13.5	" " 3402
43	8 20 22.49	+2.48	+10 37 54.4	-13.6	Sj. 3073
44	8 7 17.34	+2.58	+12 4 14.2	-14.0	A. G. Lpz. ₁ 3310
45	8 0 37.41	+2.56	+13 20 52.7	-14.0	" " 3248
46	8 0 0.97	+2.52	+13 38 34.1	-13.8	" " 3241
47	7 57 6.41	+2.48	+14 15 45.8	-13.8	" " 3209
48	7 52 11.78	+2.44	+14 33 20.8	-13.4	" " 3168
49	7 53 40.23	+2.16	+15 58 41.7	-12.7	" Berl. B. 3127
50	13 3 31.43	+2.85	+ 1 54 9.1	-15.4	" Alb. 4648
51	12 57 25.34	+2.85	+ 1 57 3.7	-15.6	" " 4625
52	13 0 8.51	+2.86	+ 2 23 5.3	-15.4	" " 4635
53	12 56 4.04	+2.84	+ 2 48 57.6	-15.3	" " 4617
54	12 56 41.70	+2.81	+ 3 17 59.7	-14.7	" " 4620
55	12 51 6.67	+2.79	+ 3 28 53.9	-14.8	" " 4605
56	12 51 35.79	+2.78	+ 3 49 57.1	-14.4	" " 4608
57	12 50 46.24	+2.73	+ 4 4 24.0	-13.6	" " 4602
58	8 17 18.14	+2.65	+23 21 8.6	-12.6	" Berl. B. 3352
59	8 28 57.54	+2.85	+30 36 24.2	-12.5	" Lei. 3570
60	8 22 38.79	+2.81	+30 48 51.3	-11.6	" " 3534
61	8 40 12.48	+2.56	+ 8 22 7.9	-15.1	" Lpz. ₂ 4770
62	8 32 39.25	+2.58	+ 9 50 50.5	-15.4	" Lpz. ₁ 3475
63	8 30 51.92	+2.58	+10 17 56.5	-15.4	" " 3455
64	8 29 36.74	+2.58	+10 51 39.7	-15.3	" " 3448
65	8 30 17.48	+2.56	+11 6 49.0	-15.3	" " 3452
66	8 26 51.41	+2.54	+12 7 32.2	-15.3	" " 3432
67	8 25 2.42	+2.51	+12 39 10.4	-15.0	" " 3420
68	12 7 26.29	+2.68	+ 7 48 53.1	-17.6	" Lpz. ₂ 6037
69	12 0 12.78	+2.68	+ 7 50 42.3	-17.6	" " 6008
70	11 41 4.21	+2.64	+ 8 16 30.5	-16.7	" " 5905
71	11 39 34.37	+2.61	+ 8 7 7.5	-16.4	" " 5895
72	8 45 24.43	+2.74	+26 39 9.8	-13.2	Cbr. E. 4704
73	10 0 57.05	+2.59	+ 9 2 35.0	-17.7	" Lpz. ₂ 5356
74	10 0 6.78	+2.55	+ 9 11 38.8	-17.6	" " 5349
75	10 51 52.37	+2.64	+ 6 36 45.7	-18.2	" " 5632
76	10 46 41.56	+2.63	+ 6 53 27.5	-18.2	Mü. ₂ 3487
77	10 40 56.79	+2.62	+ 6 59 53.6	-18.2	A. G. Lpz. ₂ 5578
78	10 41 8.85	+2.55	+ 7 23 0.2	-17.7	" " 5579
79	9 37 22.93	+2.64	+16 7 12.1	-16.6	" Berl. A. 3899
80	9 32 43.53	+2.67	+16 35 12.0	-16.5	" " 3871

On Clock Errors and Wireless Time Signals. By Professor
R. A. Sampson, Astronomer Royal for Scotland.

The data appended include a digest of observed errors of the clock Riefler No. 258 at the Royal Observatory, Edinburgh, from 1915 to 1920 October, and the observed comparisons of this clock with the scientific time signals sent out by wireless from the Eiffel Tower from 1914 to 1920. They are published as a contribution to the discussion of the reliability of time determination, and the ascription to their proper sources of the errors that occur in it. Besides, they bear upon certain statements and views which I expressed in an address, "On the Determination of Longitude by Wireless Telegraphy" (*M.N.*, 1920 May), among the Geophysical Discussions. But in the present paper no argument is based upon the results, and only such notes are added as are required to make clear their construction and bearing.

The first part, consisting of errors of the solar clock Riefler No. 258 alone, may be considered as directed to the question of the proper method of plotting or smoothing clock errors, so as to ascertain as well as possible from the whole run of clock corrections noted at any observatory what part really belongs to the going of the clock and what is extraneous to it. If the clock error be understood as meaning the departure of observation from the indication corresponding to an ideal fixed rate embracing the whole group of observations, sources that may contribute to this error are the following:—

- (a) actual fluctuations of rate in the clock, whether transitory or long continued, slow, rapid, or instantaneous;
- (b) faults of the chronographic system, by which the record of the clock or the record of the observation is made with a lag which varies from one observation to another;
- (c) errors in determination of the instrumental corrections of the Transit Circle;
- (d) errors due to catalogue places of the stars observed;
- (e) anomalies, if any, due to atmospheric causes;
- (f) accidental error of observing;
- (g) personality of observers.

Out of this list the present communication may be considered as directed first to (a), and second to (g) in the form of the comparison of clock times as accepted at Edinburgh and Paris.

From various clock errors that have been published, and analysed by different writers, I have found it as a rule very difficult to draw any conclusions. They usually deal with selected runs, and cover short periods of time. There is nothing to show that the coefficients of change that are found to apply could be considered permanently representative. It is much to be desired that a simple standard method of plotting or smoothing should be agreed upon, one that could be applied continuously and permanently

to the whole sequence of clock errors as they are determined, and the indications of which admit of being readily interpreted so as to supply a comparison of the same clock at two epochs, or of two different clocks with one another. Recognising that no clock goes permanently without fault, the simplest of all suppositions is that of a dead smooth rate broken suddenly and replaced by another, different but also constant. The graph of the clock corrections would then be a rectilinear figure with sharp angles. If the observed clock corrections are plotted and such an analysis applies at all, it is an easy matter to assign the corners of this figure—it is a thing done with certainty; whereas if curvature, even of the simplest parabolic kind, is admitted, there will be many cases of doubtful judgment; and the rest of the calculation is of the simplest possible kind. There will then be three data to assign, in order to describe the going of the clock: (1) the dates at which the rate changes, (2) the fixed rates held between these dates, and (3) the mean departure of observation from the rectilinear graph expressing (1) and (2). An analysis of this kind applied to the Edinburgh clock is given in the table below. The fixed rate is called the *base rate* of the clock between any two dates of change; the clock is kept at constant temperature, and when the barometric pressure within the case is altered in order to bring the clock to time, the base rate is deduced from the observed rate by applying the correction $1 \text{ mm.} = +0.0167 \text{ per day}$. This coefficient was derived by experiment. On a few occasions the control of temperature broke down. In cases where the break of temperature was small, it is allowed for at the scale $1^\circ \text{ C.} = +0.004 \text{ per day}$, being a coefficient also derived by experiment; larger breaks are treated as interruptions of the series. The departure, No. (3) above, presumably includes the whole of the errors (b)–(g) enumerated on p. 89, besides anything due to fluctuations in the going of the clock which are out and beyond a fixed base rate; but excepting that part, if any, of (d), which is seasonal, and so runs into successive nights' observations in the same degree.

The following is the arrangement of the table. It divides naturally into sections marked by interruptions of the running. The first goes from 1915 Jan. 0 to 1916 Feb. 19, when an accidental disturbance of the case, throwing the clock off beat and causing a large losing rate to be taken on, gave an occasion for stopping and cleaning it. During this period the base rate is given relative to a barometric pressure of 585 mm. After Mr. Cottingham had cleaned the clock the second section runs from 1916 March 27 to 1917 Nov. 7. The base rate is now relative to a barometer of 600 mm., so that after cleaning the clock may be said to have gone faster by 0.025 per day than before (and still faster relatively to the losing rate taken on after disturbance of the case). The first two groups of this run are treated as unsettled, and are excluded from the means. This section of the run was terminated by an accident which fused a wire within the clock, preventing it from sending any signals but not otherwise disturbing

it. It was opened, the pendulum was allowed to stop, locked and raised from its agate supports, and the wire replaced, and on closing up it was found that the clock had taken on a large losing rate; the base rate thereafter is accordingly taken relative to a barometer of 630 mm., representing a change of $0^s.50$ per day. It has run under these circumstances from 1917 Nov. 14 to the present date, and the subsequent divisions into sections are merely matters of convenience. They are taken at 1918 Dec. 31, 1919 Dec. 23, and for the present publication 1920 Oct. 30.

The process of deriving the numbers is the following:—The clock error as given, unsmoothed, from T.C. observations of each night is marked on a graph. This graph is regarded as representing a series of straight lines meeting at sharp angles, and the positions of the corners or intersections corresponding to changes of rate are put in by eye. The plotted error is given by the straight lines joining these corners. Whenever an observation is available, the “erratic” is the observed error *minus* the plotted error; the slope of the plotted error gives the rate of any group, and this rate, corrected to reduce it to standard barometric condition (and for small changes of temperature, if any), is the base rate. No cause can be assigned for changes of the base rate from one group to the next, and such as they are they must be considered as faults in the clock, or of its circumstances. The groups appear to have a definite mean length and the changes of base rate a definite mean value; each has also a fairly definite maximum, running to about two or three times the mean; accumulation of changes of rate results in the base rate ranging on each side of its mean in each section by a certain span. The values of the mean erratics, and their ascription to their proper causes, is not the subject of the present paper, but they are recorded, as well as the number of T.C. determinations upon which they rely, to show that they are of proper amounts. Each T.C. determination depends, as a standard, upon ten clock stars and at least two polars. The ephemeris places have been reduced to the system of the Preliminary General Catalogue of Boss.

It appears to me that this analysis gives a good idea of the behaviour of the clock. The test of its applicability is the duration of the groups, each group being supposed to include a sufficient number of T.C. determinations.

Riefler No. 258, Base Rate and Erratics: collected.

From	1.	2.	3.	4.	5.	6.
	Date.	Duration of Group.	Base Rate [585 mm. 17° 6].	Change of Rate.	Mean Erratic.	No. T.C. Observa- tions.
		d	s	s	s	
1915 1	Jan. 0	26	+ '051		± '052	16
2	26	41	+ '030	- '021	'028	16
3	Mar. 8	16	+ '060	+ '030	'033	8
4	24	12	- '010	- '070	'027	7
5	Apr. 5	17	+ '044	+ '054	'017	11
6	22	18	+ '014	- '030	'027	6
7	May 10	12	+ '029	+ '015	'020	5
8	22	9	+ '053	+ '024	'017	3
9	31	9	+ '031	- '022	'016	5
10	June 8	11	- '006	- '037	'015	9
11	19	20	+ '015	+ '021	'034	5
12	July 9	7	+ 009	- '006	'030	5
13	16	22	+ '006	- '003	'015	9
14	Aug. 7	7	- '011	- '017	'026	5
	14	—	—	—	—	—
	19	—	—	—	—	—
15	Sept. 8	20	+ '039	- '035	'024	10
16	13	5	+ '004	- '004	'007	3
17	24	11	'000	+ '002	'016	5
	—	—	+ '002	—	—	—
	27	13	+ '018	+ '016	'026	11
18	Oct. 10	28	- '029	- '047	'039	10
19	Nov. 7	19	+ '007	+ '036	'030	14
20	26	6	+ '053	+ '046	'025	2
21	Dec. 2	28	+ '036	- '017	'026	9
22	30	—	—	- '053	—	—
1916 1	Jan. 7	8	- '017	+ '021	'023	4
2	17	10	+ '004	- '064	'023	3
3	27	10	- '060	+ '076	'018	5
4	Feb. 2	6	+ '016	—	'010	3
	—	—	—	—	—	—
	4	5	- '002	—	'030	4
5	9	10	+ '035	+ '037	± '010	4
	19	—	—	—	—	—

R. Base Rate and Erratics: collected.

After cleaning by E.T.C.	1. Date.	2. Duration of Group. d	3. Base Rate [600 mm. 17°'6]. ■	4. Change of Rate. s	5. Mean Erratic. s	6. No. T.C. Observa- tions.
1916	7 Mar. 27	19	- '255		± '040	12
	8 Apr. 15	7	- '234	+ '021	—	—
	9 22	6	- '161	+ '073	'040	3
	10 28	12	- '128	+ '033	'060	2
	11 May 10	20	- '117	- '011	'040	11
	12 30	28	- '142	- '027	'036	10
	13 June 27	24	- '186	- '044	'020	8
	14 July 21	13	- '146	+ '040	'020	8
	15 Aug. 3	17	- '099	+ '047	'020	2
	20	—	—	+ '018	—	—
	16 Sept. 1	6	- '081	—	'027	3
	7 7	18	- '102	- '021	'031	8
	17 25	14	- '117	- '015	'057	6
	18 Oct. 9	22	- '141	- '024	'035	13
	19 31	8	- '170	- '029	'035	4
	20 Nov. 8	24	- '157	+ '013	'056	5
	21 Dec. 1	13	- '108	+ '039	'013	3
	22 14	14	- '093	+ '015	'023	6
	23 28	9	- '092	'001	'020	3
	24 Jan. 6	—	—	—	—	—
1917	1 Feb. 13	13	- '015	— '004	'020	3
	2 26	11	- '011	- '014	'020	4
	3 Mar. 9	21	- '025	- '028	'036	11
	4 30	10	- '053	+ '001	'030	2
	5 Apr. 9	17	- '052	+ '001	'066*	8
	6 26	9	- '035	- '052	043	6
	7 May 5	10	+ '017	- '052	—	—
	8 15	13	- '029	- '046†	'084	5
	9 28	7	- '054	- '025	'027	3
	10 June 4	12	- '067	- '013	'033	6
	11 16	7	- '037	+ '030	'035	2
	12 23	6	- '069	- '032	'030	4
	13 29	15	- '033	'036	'028	4
	14 July 14	16	- '013	+ '020	'043	4
	30	—	—	—	—	—

* One erratic - s°24.

† Workmen fixing fan in clock chamber.

R. Base Rate and Erratics: collected—continued.

After cleaning by E.T.C.	1.	2.	3.	4.	5.	6.
	Date.	Duration of Group.	Base Rate [600 mm. 17°'6].	Change of Rate.	Mean Erratic.	No. T.C. Observa- tions.
		d	s	s	s	
1917 15	Aug. 22	24	+ '049		'029	10
16	Sept. 15	11	+ '071	+ '022	'054	5
17	26	8	+ '114	+ '043	'008	4
18	Oct. 4	14	+ '082	- '032	'063	6
19	18	9	+ '070	- '012	'010	2
20	27	11	+ '107	- '037	± '030	3
—	Nov. 7					
R. opened to replace fused wire.						

R. Base Rate and Erratics: collected.

No.	1.	2.	3.	4.	5.	6.
	Date.	Duration of Group.	Base Rate [630 mm. 17°'6].	Change of Rate.	Mean Erratic.	No. T.C. Observa- tions.
		d	s	s	s	
1917 21	Nov. 14	14	+ '140	+ '033	± '083*	4
22	28	5	+ '066	- '074	'030	2
23	Dec. 3	12	+ '042	- '024	'025	4
24	15	18	- '002	- '044	'050	5
	Jan. 2			- '059		
1918 1		6	- '061		'030	4
2	8	8	+ '001	+ '062	'000	2
3	16	12	+ '009	+ '008	'030	2
	28					
4	Apr. 1	8	- '051		'005	2
5	9	34	- '011	+ '040	'031	7
6	May 13	15	- '013	+ '002	'060	5
7	28	20	+ '006	+ '019	'023	6
8	June 18	18	- '003	- '009	'045	2
9	July 6	19	+ '005	+ '008	'020	2
10	25	5	'000	+ '005	'053	3
11	30	28	- '016	- '016	'033	6
12	Aug. 27	29	+ '012	+ '028	'068	4
13	Sept. 25	47	+ '012	'000	'046	10
14	Nov. 11	10	+ '010	- '002	'063	4
15	21	8	+ '046	+ '036	'025	2
16	29	16	+ '017	- '029	'055	4
17	Dec. 15	16	- '029	- '046	'043	3
	31					

* One erratic + s. 19.

R. Base Rate and Erratics : collected.

No.	I. Date.	2. Duration of Group. d	3. Base Rate [630 mm. 17°·6]. s	4. Change of Rate. s	5. Mean Erratic. s	6. No. T.C. Observa- tions.
1919	1 Jan. 2	20	- '018	- '009	'040	4
	2 22	17	- '027		'000	2
	3 Feb. 8	—	—	—	—	—
	4 19	10	- '013	- '041 *	'033	4
	5 Mar. 1	22	- '054	- '023	'031	7
	6 23	34	- '077	- '032	'017	3
	7 Apr. 26	18	- '109	- '026	'053	3
	8 May 14	12	- '135	+ '040	'020	2
	9 26	14	- '095	- '032	'042	6
	10 June 9	28	- '127	+ '012	'020	5
	11 July 7	18	- '115	+ '009	'038	5
	12 25	15	- '106	- '011	± '050	8
	13 Aug. 9	27	- '117	+ '036		
	14 Sept. 5	27	- '081			
	15 Oct. 2	19	- '072	+ '025	± '058	6
	16 Oct. 21	6	- '047	- '015	'013	3
	17 27	15	- '062	+ '013	...	...
	18 Nov. 11	23	- '049	+ '020	'042	6
1920	1 Dec. 4	19	- '029	- '012	'032	5
	2 23	23	- '041	+ '013	'064	5
	3 Jan. 15	15	- '028	+ '011	'047	6
	4 30	32	- '017	+ '037	'064	16
	5 Mar. 2	20	+ '020	- '017	'060	6
	6 22	18	+ '003	+ '015	'033	3
	7 Apr. 9	21	+ '018	+ '013	'044	5
	8 30	10	+ '031	- '039	'053	4
	9 May 10	18	- '008	+ '020	'043	7
	10 28	10	+ '012	- '022	'050	2
	11 June 7	10	- '010	+ '010	'043	6
	12 17	5	'000	+ '033	'055	2
	13 22	18	+ '033	+ '029	'040	6
	14 July 10	16	+ '004	+ '007	'038	4
	26	40	+ '011	+ '042	'027	10
	14 Sept. 4					

* Temperature disturbed.

R. Base Rate and Erratics : collected—continued.

No.	Date.	1.	2.	3.	4.	5.	6.
			Duration of Group.	Base Rate [630 mm. 17°·6].	Change of Rate.	Mean Erratic.	No. T.C. Observa- tions.
			d	s	s	s	
1920 15	Sept. 13		9	+ '053	- '025	'065	2
16	22		9	+ '028		'035	4
	25*		...	...	...	...	...
17	30		5	+ '081	- '014	...	...
18	Oct. 12		12	+ '067	- '001	'033	4
19	30		18	+ '066		'037	10

Base Rate and Erratics : Summary.

1.	2.	3.	4.	5.	6.	7.	8.	9.
Section.	Barometric Standard.	Mean Base Rate.	Range of Base Rate.	Greatest Change.	Mean Change.	Mean Dura- tion.	Mean Erratic.	Average No. T.C. Observa- tions.
		s	s	s	s	d	s	
1915 Jan. 0	585 mm.	+ '016	'120	'076	± '031	15	± '024	7
-1916 Feb. 19			cleaned					
1916 Apr. 22	600 mm.	+ '056	'300	'052	± '025	14	± '035	7
-1917 Nov. 7			opened to replace fused wire					
1917 Nov. 14	630 mm.	+ '016	'201	'074	± '026	16	± '039	4
-1918 Dec. 31								
1919 Jan. 2	630 mm.	- '071	'124	'041	± '023	19	± '033	5
- Dec. 23								
1919 Dec. 23	630 mm.	+ '017	'122	'042	± '020	16	± '044	6
-1920 Oct. 30								

The foregoing results, relating to the run of the standard clock of the Observatory, have been compressed as much as possible, because the object was to convey in a small compass a complete summary of continuous performance. There now follow the W.T. comparisons with Paris. It is desirable these should be given in much more detail, because very little has been published about such observations so far. But the whole material is too voluminous for the present publication, and it is hoped that a specimen page of the detail, accompanied by an abstract and summary of the whole, may give a reliable impression. Its interest lies in its bearing on the question of the consistency of two determinations of time, that is, of the phase of the earth's rotation, each made with all care at different places and under different circumstances. It is a question at the base of longitude determination, but from an astronomical point of view longitude itself, as being a quantity wholly terrestrial, is less important than the more abstract question of consistency. As before, no discussion is appended. The data are offered as a contribution ; conclusions

* Temperature disturbed.

should not be drawn till the cumulative outcome from similar comparisons at several places are available.

The comparisons run from 1914 March to the end of October of the current year 1920, with a few short interruptions. They are made by means of the scientific time signals, or time verniers, exclusively. They were made every day, until pressure of war circumstances enforced a restriction, and they were then made generally only when T.C. observations for time were also obtained at the Observatory; daily observations were resumed in the present year. The outcome of the observation "Paris minus Edinburgh," with sign + for the Edinburgh clock slow, may be considered to embrace the following elements:—

- (a) error in the reputed relative longitude of Paris and Edinburgh;
- (b) errors in the reputed time at Paris;
- (c) the like at Edinburgh.

The longitude adopted for Edinburgh is $12^{\text{m}} 44^{\text{s}}.2$ W.

If the results converged upon a consistent constant mean, it would be attributed naturally to (a). As regards (b), the Paris time taken is that transmitted in connection with the W.T. signal, without applying any correction. With regard to (c), the operation of comparison is the following:—The reading of the clock Riefler No. 258 is made upon the chronograph; it is also plotted as described in the preceding pages. Riefler drives a slave clock which makes a contact from its pendulum at the lowest point of its swing, which is registered as a tick in the telephone in the wireless room; coincidences between the time vernier and this tick are noted by ear, an arrangement being provided for reducing them to suitable strength. This plan introduces into the observation the lag between the chronograph indication and tick of the slave clock. Some experiences of the determination of this lag with the microchronograph are given in *Mon. Not.*, 1918 June, p. 610, "On the Measurement of Time to the Thousandth of a Second." The lag will change where there is a change in the adjustments, but appears to be very steady under ordinary unchanged circumstances. It might be anticipated also that some allowance for personality would enter; but many experiments with two observers taking the same ticks with duplicate telephones, showed that they always agreed as to where the coincidences fell. There is therefore no personality to be allowed for.

After these explanations the arrangement of the table from which the appended extract is taken explains itself. The extract covers the section 1915 Oct. 8 to Nov. 29, and appears to me fairly representative of the whole. When the observation is corrected for lag and Edinburgh time taken as plotted, the outcome as given by column 7 would be presumed to be cleared from errors so far as one observatory is able to assign them. Following the extract is a summary and abstract of the whole table, showing the results section by section. The whole of the run is supposed

to be on a comparable footing, and division into sections is an arbitrary matter governed by convenience. The aim with which it is made is to allow formation of a judgment as to whether or not these comparisons promise a satisfactory convergence upon a definite constant result.

On reading the numbers through, I think it will be felt that such a convergence is fairly decisive, in spite of a rather wide range. The general mean, Paris *minus* Edinburgh, is $+^{\circ}060$. The lowest value shown over a year is $+^{\circ}02$, and the highest are $+^{\circ}12$ and $+^{\circ}11$ in 1914 and 1920 respectively. The latter is produced by a long series of large values running from June to September, some of which seem anomalous. It must be recalled that the Paris times employed are provisional, being those sent out at the time of observation, and therefore dependent during cloudy weather upon extrapolation. It may be presumed that revised values would make the sequence somewhat smoother.* But it would hardly sensibly alter the mean, as may be inferred by noting that the general mean when the Edinburgh clock errors are taken directly as observed is $+^{\circ}056$, which is sensibly the same as that given by the plotted errors, $+^{\circ}060$.

The least satisfactory feature of the comparison is the persistence of values substantially different from the general mean over substantial periods of time, as the low values of 1916 and the high values from June to September of the present year. Another feature that will require scrutiny is a fairly pronounced tendency to show larger values in the middle of the year than at the ends. The series, however, is hardly long enough to decide whether the latter appearance is a real seasonal fault or merely an accident. When more material has been published it will be easier to tell where to look for the causes of anomalies. It ought to be possible by exchange of experience at different observatories to avoid such semi-systematic divergences; the best plan would be to record daily at several observatories the receipt of the same signals over considerable intervals of time. Comparisons for short durations are inconclusive.

The present position is a curious one, and invites improvement. The clock errors at a single observatory are less accordant with one another from day to day than a scrutiny of the individual T.C. observations would lead one to expect; and the comparison of clock errors of two observatories show still greater discordances, and such as require a long span of time to efface their effects in the mean.

Thus the mean erratic at Edinburgh as shown by the previous table is $\pm^{\circ}035$; the average departure from mean, section by section, shown below in the comparison of Paris and Edinburgh, is $\pm^{\circ}06$, being a little more than $\sqrt{2} \times$ the former value, which one would expect on introducing the separate erratics of the two observatories; but if we took the departure, not section by section, but from the general mean, it is evident that the amount would be much increased.

* This is borne out by employing the corrections for 1920 Jan. 1–March 18, published by M. Bigourdan in *Comptes Rendus* (1920), t. 171, p. 645.

EXTRACT FROM TABLE.
W.T. Comparisons. Paris and Edinburgh.

1915.	1. Observed Signal.	2. Lag.	3. Corrected Signal.	4. Observed Clock Error.	5. Plotted Clock Error.	6. Paris minus Edinburgh.	
						(3)-(4).	(3)-(5).
	^s	^s	^s	^s	^s	^s	^s
Oct. 8	+ '44	+ '08	+ '36	...	+ '37	...	- '01
9	+ '51		+ '43	...	+ '40	...	+ '03
11	+ '44		+ '36	+ '41	+ '40	- '05	- '04
12	+ '41		+ '33	...	+ '38	...	- '05
13	+ '38		+ '30	+ '31	+ '36	- '01	- '06
14	+ '39		+ '31	+ '35	+ '34	- '04	- '03
15	+ '44		+ '36	+ '39	+ '32	- '03	+ '04
16	+ '38		+ '30	+ '34	+ '30	- '04	'00
18	+ '38		+ '30	...	+ '26	...	+ '04
19	+ '38		+ '30	...	+ '24	...	+ '06
20	+ '35		+ '27	...	+ '22	...	+ '05
21	+ '32		+ '24	+ '22	+ '20	+ '02	+ '04
22	+ '29		+ '21	...	+ '18	...	+ '03
25	+ '21		+ '13	...	+ '12	...	+ '01
26	+ '22		+ '14	+ '05	+ '10	+ '09	+ '04
27	+ '21		+ '13	...	+ '08	...	+ '05
28	+ '22		+ '14	...	+ '06	...	+ '08
29	+ '22		+ '14	'00	+ '04	+ '14	+ '10
30	+ '22		+ '14	- '04	+ '02	+ '18	+ '12
Nov. 1	+ '21		+ '13	...	'00	...	+ '13
2	+ '12		+ '04	+ '02	- '02	+ '02	+ '06
3	+ '05		- '03	...	- '04	...	+ '01
5	- '07		- '15	...	- '08	...	- '07
6	- '04		- '12	...	- '10	...	- '02
7	...		...	- '15	- '15	...	...
8	- '01		- '09	...	- '12	...	+ '03
9	- '01		- '09	...	- '10	...	+ '01
10	- '03		- '11	- '09	- '08	- '02	- '03
11	+ '04		- '04	- '03	- '05	- '01	+ '01
12	+ '02		- '06	- '08	- '03	+ '02	- '03
13	- '01		- '09	+ '03	- '01	- '12	- '08
15	+ '09		+ '01	+ '02	+ '04	- '01	- '03
16	+ '06		- '02	+ '08	+ '07	- '10	- '09
17	+ '12		+ '04	+ '06	+ '09	- '02	- '05
18	+ '20		+ '12	+ '09	+ '11	+ '03	+ '01
19	+ '19		+ '11	+ '08	+ '14	+ '03	- '03
20	+ '22		+ '14	+ '11	+ '16	+ '03	- '02
22	+ '27		+ '19	+ '16	+ '21	+ '03	- '02
23	+ '27		+ '19	+ '23	+ '23	- '04	- '04
24	+ '29		+ '21.	...	+ '25	...	- '04
25	+ '34		+ '26	+ '23	+ '28	+ '03	- '02
26	+ '36		+ '28	+ '31	+ '31	- '03	- '03
29	+ '46		+ '38	...	+ '42	...	- '04

The means of column 6 and column 7, in each case $s^{\circ}00$, as well as the average variation from these means, $\pm s^{\circ}05$ and $\pm s^{\circ}04$ respectively, are carried to the Summary that follows.

SUMMARY OF TABLE.

W. T. Comparisons. Paris minus Edinburgh.

Section.	Observed Clock Errors.			Plotted Clock Errors.		
	No. of Days.	Means for Section and [Year].	Average Variation from Mean.	No. of Days.	Means for Section and [Year].	Average Variation from Mean.
1914 Mar. 14-May 2	30	+ '11	± '05	40	+ '10	± '06
May 4-June 19	21	+ '12	'07	38	+ '12	'08
June 20-Aug. 2	22	+ '17	'06	34	+ '15	± '06
		[+ '132]			[+ '121]	
1915 Mar. 12-May 5	23	+ '03	± '04	37	+ '03	± '04
May 6-June 25	23	+ '08	'04	41	+ '08	'04
June 26-Aug. 18	20	+ '06	'02	39	+ '07	'02
Aug. 19-Oct. 7	28	+ '05	'04	41	+ '06	'03
Oct. 8-Nov. 29	24	'00	'05	42	'00	'04
Nov. 30-Dec. 30	6	+ '03	± '03	20	+ '10	± '06
		[+ '044]			[+ '053]	
1916 Jan. 3-Feb. 19	22	+ '01	± '04	37	+ '01	± '03
Mar. 17-Apr. 26	17	+ '02	'03	33	+ '04	'07
Apr. 27-June 19	19	'00	'06	40	+ '02	'06
June 20-Aug. 20	19	+ '02	'07	41	+ '02	'05
Aug. 31-Oct. 28	22	+ '04	'06	36	+ '03	'06
Oct. 30-Dec. 30	17	'00	± '08	42	'00	± '08
		[+ '015]			[+ '020]	
1917 Jan. 1-Mar. 9	17	- '03	± '05	35	- '05	± '05
Mar. 12-May 24	23	+ '03	'08	34	+ '02	'08
May 26-Sept. 1	22	+ '07	'04	32	+ '06	'04
Sept. 3-Nov. 27	18	+ '03	'06	30	+ '03	'07
Nov. 29-Dec. 27	5	- '02	± '10	10	+ '02	± '04
		[+ '023]			[+ '016]	
1918 Jan. 1-Jan. 28	6	- '06	± '07	8	- '04	± '08
Mar. 25-July 9	12	+ '09	'08	17	+ '08	'06
July 27-Aug. 30	5	+ '19	'01	5	+ '17	'03
Oct. 4-Dec. 31	11	'00	± '06	12	+ '01	± '06
		[+ '052]			[+ '048]	
1919 Jan. 2-Apr. 26	14	+ '06	± '06	15	+ '07	± '06
July 9-Oct. 2	15	+ '07	'09	18	+ '09	'10
Oct. 6-Dec. 29	23	+ '05	± '07	25	+ '04	± '05
		[+ '050]			[+ '061]	
1920 Jan. 8-Apr. 25	27	+ '01	± '07	41	- '03	± '09
Apr. 26-June 13	15	+ '08	'07	42	+ '06	'06
June 14-Aug. 3	16	+ '19	'14	42	+ '21	'13
Aug. 4-Sept. 22	13	+ '13	'16	42	+ '19	'14
Sept. 23-Oct. 31	13	+ '17	± '05	28	+ '14	+ '04
		[+ '101]			[+ '114]	

GENERAL MEAN.

1914-20

568

+ '056

997

+ '060

Note on the Longitude of Adelaide. By G. F. Dodwell,
Government Astronomer.

Thanks to the kindness of General Ferrié, rhythmic signals were sent out from Lyons between June 21 and July 5. It was found possible to receive these signals at Adelaide. A comparison with the times received at Greenwich gives the following results:—

	h	m	s
June 23	9	14	19.95
24			20.15
25			20.11
28			20.03
29			19.90
30			19.92
July 1			19.94
4			20.03
5			19.91
Mean	9	14	19.99

Allowing for time of transmission $0^s.04$, this makes the longitude of Adelaide

$$9^h 14^m 19^s.95,$$

which may be compared with the adopted value,

$$9^h 14^m 20^s.07.$$

A series of Annapolis signals received at Adelaide and Greenwich from July 6 to 28 gives

$$9^h 14^m 19^s.79,$$

while a second series from August 8 to 19 gives

$$9^h 14^m 19^s.78.$$

These are, however, not direct comparisons, as Adelaide received the signals sent at 3^h Greenwich Civil Time, and Greenwich those at 17^h . But the regularity of the Annapolis signals makes the results worthy of record.

On the Einstein Terms in the Motion of the Lunar Perigee and Node. By W. de Sitter.

In my second paper "On Einstein's Theory of Gravitation, and its Astronomical Consequences," the general formula for the motion of the lunar perigee and node * is obviously erroneous. It should read :

$$(97) \quad \delta\varpi = \delta\Omega = \frac{3}{2} \frac{m\lambda_1^2}{\rho} \frac{v_0}{v} nt = \frac{3}{2} \frac{\lambda_0^2}{\rho} n_0 t,$$

where we have used $a^3 v = \lambda_1$ (not $a^3 \lambda_1 = v$ as printed!). The numerical value given, viz.

$$+ 1'' \cdot 91 \text{ per century,}$$

corresponds to the *correct* formula. The comparison with observations is therefore not affected.

It appears from the second form given above that the motion depends only on the elements of the earth, and not on those of the moon. In a paper which will soon be published in the *Proceedings* of the Academy of Sciences at Amsterdam, Dr. A. D. Fokkes finds the same motion from the following considerations: he introduces a system of axes which takes part in the motion of the earth, the time-axis being always tangent to the earth's world-line (so that the "time" is the proper time of the earth), and the space-axes remaining perpendicular to the time-axis and parallel to themselves. He shows (1) that with reference to these axes the equations of motion are, with sufficient approximation, Newtonian; and (2) that these axes have a precessional motion with regard to axes fixed in the Sun, amounting to $\frac{3}{4} \cdot \frac{a}{\rho} \cdot 2\pi$ yearly. Since his a is the same as my $2\lambda_0^2$, this is exactly the formula (97).

Arosa :
1920 November 12.

* *M.N.*, 77, 172.